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VILDLIFE OF THE PRAIRIES AND PLAINS

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WILDLIFE OF THE PRAIRIES AND PLAINS

Keith E. Evans and George E. Probasco

The extensive and diverse grasslands of North America were maintained and perpetuated under the land use policies of the aborigines. Grasses dominated the low rainfall Great Plains for many thousands of years and still do except where cultivation or destructive grazing have occurred. Fire was required in the higher rainfall prairie and savannah areas to control woody plant encroachment. Some of the wildlife species adapted to these grasslands included bison, antelope, elk, bear, rabbits, prairie dogs, wolves, coyotes, and grouse. The river bottoms and badlands in the area provided habitat for deer, Audubon's bighorn sheep, bobcat, mountain lion, turkey, quail, and waterfowl.

In the late 1800's the American frontier expanded westward--the day of the true "wild west". Settlement under the Homestead Act of 1862 encouraged many people to settle on the prairies and plains. In a short span of time the area changed from wild grasslands teeming with wildlife to civilized areas of farms, ranches, fences, towns, roads, and railroads. The 19th century witnessed the beginning and end of the Oregon Trail, gold rushes, open range, and cattle drives.

The wet years and high prices associated with World War I made the Great Plains look like the promised land to many farmers. However, the years of productivity and profits gained by cultivating low rainfall areas were short. First came low postwar prices, then high taxes, low rainfall, and dust. Thus began the "dust bowl" days of the 1930's.

For the most part, the economy and land use patterns on the North American grasslands have again become fairly stable. A large proportion of the original grasslands are now being cultivated. The tall grass prairie once covered 42 million acres, but now has been reduced to 18 million acres. Over much of the remaining uncultivated tall grass prairie region, livestock overgrazing has altered the plant and animal composition drastically. Extensive areas are managed for livestock production by perpetuating the native flora. These areas are inhabited by many wildlife species.

THE RESOURCE

Grasslands encompass the most extensive and varied of all plant communities in North America (fig. 1). The midcontinent grassland extends 2,500 miles north to south and averages 400 miles in width from the Rocky Mountains east as far as Illinois. It includes four of the eight major grassland types recognized in North America: (1) oak-bluestem savannah, (2) tall grass, (3) mixed grass, and (4) short grass. The remaining four are: (5) bunch grass, such as the palouse prairie in Oregon, Idaho, and Washington, (6) annual grass in the California's Central Valley, (7) desert grassland in New Mexico and Arizona, and (8) the coastal prairies in Texas, Louisiana, Maryland, New Jersey, New York, Rhode Island, and Massachusetts.

The oak-bluestem savannah stretches from southeast North Dakota and middle-west Minnesota south along the eastern edge of the tall grass prairie to mideastern Texas. It is actually the transition zone or ecotone between the eastern deciduous forest and the tall grass prairie. Scattered segments of savannah occur throughout the oak-hickory forest and the eastern part of the bluestem prairie. The bluestem-oak-hickory forest mosaic, cedar glades, and cross timber vegetation types of Kuchler's (1964) Potential Natural Vegetation Map are included as savannah. The greater part of the Ozark Dome is often included as part of the savannah (Marbut 1911, Davis 1964).

The tall grass prairie formerly occupied the ecotone between the savannah and the mixed grass prairie. Fire was an important factor in preventing the forest type from invading the prairie (Curtis

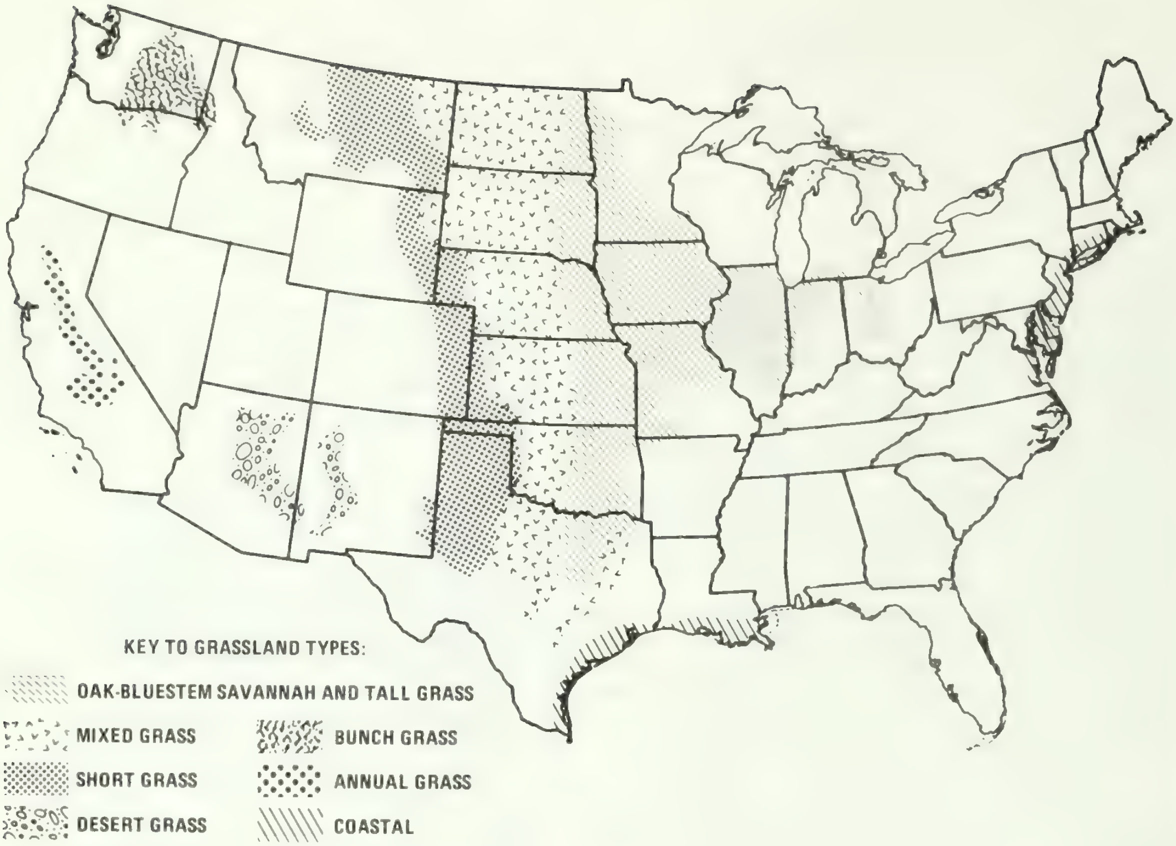

Figure 1.--*Principal grassland types of the United States.*

1959). Currently most of the tall grass prairie has been converted to forest, to mixed grass, or plowed. The conversion to mixed grass resulted from prolonged extensive livestock grazing.

The mixed grass or needlegrass-wheatgrass-grama grass (*Stipa-Agropyron-Bouteloua*) community occupies the area west of the tall grass region, nearly to the foothills of the Rocky Mountains. There is no definite line between the mixed grass and short grass (*Bouteloua-Buchloe*) vegetation types. The thin soil and low precipitation areas are dominated by the short grass species whereas the northern and eastern Great Plains areas contain a vegetation type dominated by the mixed grass species.

General aspects of the other grassland types are discussed in subsequent sections of this paper.

Terrain, Soil, and Climate

The topography of the midcontinent grasslands is variable, but generally it is moderately rolling. Some areas, such as the Red River Valley, are virtually flat; other areas (river breaks) along the major drainages are steep. Major soil groups include Alfisols, Mollisols, Vertisols, Inceptisols, and Aridisols. There is a gradient from the cool, moist soils in the northeast to the warm, dry soils in the southwest.

Climate of the midcontinent grasslands is temperate and subject to extreme fluctuations. Summers in the north are hot and winters are cold while in the south winters are less severe. Temperatures range from -40 C to +40 C in the north and from -10 C to +40 C in the south (Kincer 1941). The frost-free season ranges from less than 4 months in the north to nearly the entire year in southern Texas.

When periodic droughts occur, the precipitation failure usually occurs in July and August. During these droughts rainfall will vary from 50 to 90 percent of normal (Borchert 1950). Average annual precipitation varies from 115 cm in the savannah to 65-80 cm in the tall grass prairie, to 50 cm in the mixed grass prairie, and to less than 35 cm in parts of the short grass prairie. Evaporation is a significant factor in midcontinent grassland climate. Except in the savannah and tall grass prairie, the evaporation potential exceeds precipitation. Strong winds prevail over the grasslands inducing high evaporation rates and exerting considerable influence on the thermoregulatory behavior of homeothermic wildlife. Winds often become more intense during drought periods (Borchert 1950).

The other grassland areas have different climates. The coastal prairies are wet, humid, and generally mild, and not subject to the temperature extremes of the intercontinental areas. Annual precipitation for the coastal prairies ranges from 100 to 140 cm. Average annual temperatures in the northern areas range from a low of 0 C to a high of 25 C, while in the southern areas temperatures range from 13 C to 30 C. The bunch grass (palouse) prairie receives most of its moisture in the form of winter snow. The California Central Valley and desert grasslands usually receive winter rain with hot, dry summers. Annual precipitation in these grasslands is generally 50 cm or less. Average annual temperatures in the bunch grass prairie range from -5 C to 25 C. In the latter two grassland areas the temperature range is 5 C to 27 C (Kincer 1941).

Vegetation

Weaver (1954) summarized the impacts of drought and Daubenmire (1968) of fire on grasslands. Under extended drought conditions, the grass cover is reduced and the plant species composition altered (Albertson *et al.* 1957, Coupland 1958).

Fire, which frequently accompanies the drought, makes additional demands upon the vegetation. Some woody plants such as black oak (*Quercus velutina*), eastern redcedar (*Juniperus virginiana*), and ashe's juniper (*Juniperus ashei*) are particularly vulnerable to fire.

Native Americans and early settlers utilized fire to attract and hold game and to prepare the range for early spring grazing. Fire suppression efforts early in this century effectively reduced the use of fire for these purposes. However, research in the Kansas Flint Hills (Anderson *et al.* 1970), Missouri (Kucera and Koelling 1964), and Texas (Wright 1974a, 1974b) reveal that obligate relations may exist between fire and some grassland plants.

Drought, fire, cultivation, and grazing all influence vegetation composition. The influence of the vast herds of bison is probably the least understood influence. For example, there is disagreement as to the successional status of the short grass plains. Many, including Shelford (1963), distinguish the short grass type as a distinctive unit (climax vegetation type). Weaver and Albertson (1956) refer to the short grass as a disclimax reflecting past grazing use. Larson (1940) offered the following evidence to support the view that the short grass plains represent the true climax of the pristine biome:

1. Historical records indicate the large herbivores stocked the plains to carrying capacity and the introduction of livestock was merely a substitution for grazing by wildlife.

2. Explorers and pioneers referred to the short grass plains long before livestock was introduced.

3. The marked ability of the short grass dominants to withstand grazing, indicating they evolved with grazing as an environmental factor.

Regardless, bison stocking rates probably varied from extremely heavy use to no use because fences were not present to restrict bison grazing. Moreover, the grasslands in presettlement times probably were subjected to frequent and erratic periods free of grazing during which changes in vegetation occurred because of climatic or moisture conditions.

Overgrazing by bison, however, probably did encourage the growth of short grass species and produced conditions favoring the "invasion" of some annual or biennial species.

The former tall grass, oak-bluestem savannah, and mixed grass types today make up one of the most productive crop-growing regions in the world: the first two combined are known as the "Corn Belt"; the third, the "Wheatland". The vegetation of those portions of these areas still remaining in grass has often been altered because cool season species have been planted to replace native warm season grasses.

A vegetation gradient, corresponding to the soils gradient, occurs across the midcontinent grasslands from east to west and from north to south. Ecologists divide the area into several vegetation types, however, the ecotones or transition zones between types are wide, variable, and depend on past land use and climatic conditions. Much of the region is actually a mosaic of several types. A wide diversity of plants occur on the grasslands. The following discussion is limited to a few of the dominant species.

Big bluestem (*Andropogon gerardi*)[1] is the dominant component in the oak savannah and tall grass prairie. Big bluestem also occurs on better sites throughout the mixed grass prairie. Sand bluestem (*A. hallii*), a close relative of big bluestem, occurs on sandy soils in the tall, mixed, and short grass prairie. Little bluestem (*A. scoparius*) dominates the drier, upland portions of the savannah and extends its range westward to become an important dominant throughout the mixed grass prairie. Little bluestem is a warm season bunch grass that commonly provides excellent cover for many wildlife species. There are many more species of *Andropogons*, but the only other one noted here is broomsedge (*A. virginicus*), which commonly occurs on old fields and overgrazed pastures in the east.

Other warm season grasses associated with the tall grass prairie include switchgrass (*Panicum virgatum*) and Indian grass (*Sorghastrum nutans*). Prairie cordgrass (*Spartina pectinata*) occurs around the prairie marshes and along the drainage systems throughout the tall and mixed grass prairie. Warm season grasses also dominate the short grass areas. Blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*) occur on the dry and abused sites throughout the mixed grass area and dominate the short grass plains.

The mixed grass prairie contains components of the tall grass prairie on the better sites and species from the short grass plains on the thin soil or dry sites or where abusive grazing has been practiced. There also are a number of grass species that reach heights of 60 to 90 cm and fill the niche between the tall grasses (often over 2 m), and the short grass (less than 20 cm). These include western wheatgrass (*Agropyron smithii*), side-oats grama (*Bouteloua curtipendula*), several species of needlegrass (*Stipa* spp.), Junegrass (*Koeleria cristata*), and several species of dropseeds (*Sporobolus* spp.). Cool season grasses play an important role throughout the mixed grass prairie and are dominant on the northern Great Plains.

Herbaceous broadleafed plants (forbs) increase the range forage value and provide esthetical values to photographers and other rangeland recreationists. The composite family (Compositae) and the legume family (Leguminosae) are well represented. Common composites include sunflowers (*Helianthus* spp.),[2] rosinweeds (*Silphium* spp.), and coneflowers (*Ratibida* spp., *Rudbeckia* spp., and *Echinacea* spp.). Common legumes include leadplant (*Amorpha* spp.), false indigos (*Baptisia* spp.), prairie clovers (*Petalostemum* spp.), and *Psoralea* spp.

Common shrubs and trees occurring on the savannah and tall grass prairie include: smooth sumac (*Rhus glabra*), snowberry (*Symphoricarpos* spp.), dogwood (*Cornus* spp.), hawthorn (*Crataegus* spp.), plum (*Prunus* spp.), hazelnut (*Corylus americana*), oak (*Quercus* spp.), elm (*Ulmus* spp.), and eastern redcedar (*Juniperus virginiana*) (Aikman 1929, Bruner 1931, Curtis 1959, Kucera 1960, Weaver 1954).

Periodic droughts restrict woody plant invasion on the mixed and short grass plains to the moist areas along drainages. These woodlands provide cover, food, and landscape diversity for many wildlife species. Dominant trees include: ash (*Fraxinus* spp.), cottonwood (*Populus* spp.), willow (*Salix* spp.), elm (*Ulmus* spp.), and boxelder (*Acer negundo*). Many shrub species occupy the understory.

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[1] *Nomenclature for grasses follows Hitchcock (1950).*

[2] *Nomenclature for forbs, shrubs, and trees from Harrington (1954).*

The palouse region and California Valley were originally dominated by bunch grass species, such as bluebunch wheatgrass (*Agropyron spicatum*) and Idaho fescue (*Festuca idahoensis*). The palouse prairie is now mostly under cultivation and the California Valley has been converted to an annual grassland containing many introduced species including chess (*Bromus* spp.). The desert grasslands are dominated by curly mesquite (*Hilaria belangeri*), galleta (*Hilaria jamesii*), and grama (*Bouteloua* spp.). The coastal prairies contain mostly tall grass species such as bluestem (*Andropogon* spp.) and cordgrass (*Spartina* spp.).

Wildlife Species

Waterfowl

The destruction of waterfowl habitat lagged behind the destruction of most of the prairie by the plow because it was easier to plow the dry uplands than to drain the wetlands. Only a few years later, with the development of large equipment (early 1900's) and govermental assistance programs (1930's), large-scale drainage programs were initiated. By the 1950's, these had reduced the original wetlands in the United States from 127 million acres to 82 million acres (Linduska 1964).

Prairie potholes are the backbone of duck production in North America. The prairie potholes region, 300,000 square miles, makes up only 10 percent of the total waterfowl breeding area of this continent, yet produces 50 percent of the duck crop in an average year--more during good years (Linduska 1964).

With a few wet years the prairie potholes provide habitat for a rapidly expanding waterfowl population. Several successive drought years bring an inevitable crash. Although droughts cause short-term declines in duck numbers, they help to maintain fertility and increase pond life. These long-term advantages probably far outweight the short-term disadvantages.

Fifteen species of ducks nest commonly in the prairie pothole region. Most abundant are the mallard (*Anas platyrhynchos*),[3] pintail (*Anas acuta*), and blue-winged teal (*Anas discors*). Other species include shovelers (*Spatula clypeata*) and gadwalls (*Anas strepera*), which seek the grasslands; green-winged teal (*Anas carolinensis*), lesser scaup (*Aythya affinis*), bufflehead (*Bucephala albeola*), ring-necked ducks (*Aythya collaris*), common goldeneyes (*Bucephala clangula*), and white-winged scoters (*Melanitta deglandi*), which are more abundant in the semiforested park lands; and redheads (*Aythya americana*), canvasbacks (*Aythya valisineria*), and ruddy ducks (*Oxyura jamaicensis*), which seem content with either a park land or a prairie habitat (Linduska 1964).

Over most of the northern unglaciated mixed grass plains, natural ponds were scarce under pristine conditions. Since the early 1930's more than 300,000 stock ponds have been constructed in North and South Dakota, Minnesota, and Montana and 10,000 have been constructed on the prairie provinces of Canada. These ponds produce about 1,000,000 waterfowl each year (Linduska 1964). Duck breeding population estimates vary between 3.3 pairs per square mile (1.8 pairs per surface acre of water), according to Lokemoen (1973) and 7.0 pairs per square mile (2.3 pairs per surface acre of water), according to Bue *et al.* (1952). Broods averaged from 0.79 per acre of stock-watering pond (Lokemoen 1973) to 1.5 broods per acre of pond (Bue *et al.* 1952).

During recent years, populations of the Canada goose (*Branta canadensis*), such as those wintering on the short grass plains, have steadily increased because prairie lands have been cultivated and bodies of water impounded. Irrigation using water from these impoundments and from wells has provided large acreages of wheat, milo, and corn that offer more and better foods than do native grasses (Grieb 1970).

Upland Game Birds

Before settlement, greater prairie chickens (*Tympanuchus cupido*) were confined primarily to the tall grass prairie. Their range gradually extended westward as the native sod gave way to farms and wheat fields throughout the mixed grass prairie types (Cooke 1909). Prairie chicken populations thrived with white-man's first attempt at farming. This was attributed to the abundance of food and undisturbed nesting areas ("prairie-type" land intermingled with patch farming). With patch

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[3] *Avian nomenclature follows American Ornithologists' Union (1957).*

farming operations, prairie chicken populations peaked in Iowa about 1880 when 69 percent of the State was cultivated. By 1900, 90 percent of Iowa was cultivated and prairie chicken numbers were decreasing (Stempel and Rodgers 1961).

Prairie chickens were first recorded in North Dakota in the early 1880's (Johnson 1964) and in Colorado in 1897 (Sclater 1912). Their populations increased and flourished during the "good pinnate years" between 1900 and 1930. With the dust bowl days of the 1930's small ranches and farms were abandoned or incorporated into larger holdings. This led to large areas of intensive cultivation on the better soils and grasslands only where the soils were too sandy or the land too hilly to farm. With very little winter food on the grasslands and virtually no nesting cover on the farmlands, prairie chicken numbers decreased drastically. Prairie chicken numbers followed this same pattern over most of the Great Plains (Beck 1957, Evans and Gilbert 1963, Johnson 1964).

The lesser prairie chicken (*Tympanuchus pallidicinctus*) inhabits a small area of grassland and brushland located in northern Texas, western Oklahoma, southwestern Kansas, southeastern Colorado, and eastern New Mexico. Their populations are fairly stable. Habitat of the Attwater's prairie chicken (*Tympanuchus cupido attwateri*) is disappearing along the Texas Gulf Coast; consequently, this bird is currently listed as an endangered species. The heath hen (*Tympanuchus cupido cupido*), which formerly occupied the coastal prairies of the New England States, is now extinct.

Since pioneering days the sharp-tailed grouse (*Pedioecetes phasianellus*) has been a part of the animal life on the brushlands, park lands, savannahs, and plains of much of the northern United States and southern Canada (fig. 2). Johnson (1964) stated that sharptails probably have been in North Dakota for hundreds of years. As with the prairie chicken, sharptail numbers decreased during the drought of the 1930's, and never regained their previous high. Intensive cultivation and certain grazing practices have decreased sharptail range and populations numbers throughout most Great Plains States.

Habitats of the sharp-tailed grouse include (Aldrich 1963):

Figure 2.--*Sharp-tailed grouse have been and still are the prominant upland game bird of the northern brushlands, park lands, and plains.*

1. The climax sagebrush of the northern desert shrub area (Columbian sharp-tailed grouse).

2. The subclimax brush in the grasslands east of the Rocky Mountains and in the park lands of the Rockies (plains sharptail).

3. The oak-savannah and logged or burned areas in the east (prairie sharptail).

4. Openings in the boreal forest (northern sharptail, Alaskan sharptail, other boreal forest races).

The bobwhite quail (*Colinus virginianus*) is a savannah species, with its populations most stable in the southern two-thirds of the savannah area (Rosene 1969, Johnsgard 1973). In the northern third of the savannah, populations decrease during years of adverse climatic conditions. The bobwhite has adapted to the habitats associated with agriculture; consequently, it is abundant even in extensively cultivated areas.

The wild turkey (*Meleagris gallopavo*) is considered a forest bird; however, archeological evidence indicates that Indians in the savannah utilized the turkey for both food and ornamentation. Shortly after 1900, exploitation and habitat destruction resulted in the extirpation or near extirpation of the turkey in the savannah (Hewitt 1967). Today, as a result of State restocking programs, turkeys are found throughout all their former range as well as in areas that originally did not support wild turkeys (Sanderson and Schultz 1973). Good turkey range contains trees for roosting and trees that produce mast and fruit for food. The grasses and forbs of the understory produce seeds and habitat for insects upon which young turkeys feed. Occasionally turkeys will feed on cultivated crops. Turkeys are found in the savannah as well as along the wooded stream and river drainages throughout the mixed grass prairie.

The mourning dove (*Zenaida macroura*) (American Ornithologists' Union 1973) is primarily migratory and depends on the northern prairies and savannahs for life requirements only during the breeding season. Populations do winter in the southern grassland types, depending on food availability. Preferred habitat for the mourning dove consists of tree cover for nesting and fields with open cover for feeding. Hedgerows, shelterbelts, orchards, or woodlots provide acceptable nesting habitat (Hanson and Kossack 1963). When conifers are available, doves prefer them for nesting (Hanson and Kossack 1963, Caldwell 1964). The weak feet and bill of the mourning dove limits its feeding activities to areas of sparse cover. Harvested fields, field margins, and overgrazed pastures contain the waste grains (wheat and corn) and weeds (foxtail) preferred by the dove (Korschgen 1958, Hanson and Kossack 1963, Ward 1964).

Nongame Birds

Predatory birds have suffered because of man's ignorance and apathy. Overzealous control programs and pesticide use have seriously reduced some species populations and caused others to be placed on the endangered and threatened species list. As one becomes knowledgeable of the feeding habits of these birds, it is evident that they, too, are important components in the biotic communities to which they belong.

Birds of prey occurring in grasslands include the red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*B. swainsoni*), rough-legged hawk (*B. lagopus*), sharp-shinned hawk (*Accipiter striatus*), and American kestrel (*Falco sparverius*). The large hawks feed on rabbits, small mammals, and snakes, the small hawks and falcons on small mammals and birds, snakes, and insects. In addition to their importance in food chains, these birds contribute to man's pest control efforts. The nocturnal raptors include the great horned owl (*Bubo virginianus*), short-eared owl (*Asio flammeus*), long-eared owl (*Asio otus*), and burrowing owl (*Speotyto cunicularia*). Many other avian species occur on the grasslands. Their role and function in grassland ecosystems is discussed in Wiens and Dyer (1975).

Bison

The American bison (*Bison bison*)[4] was the one feature of the North American central grasslands that all historians, naturalists, trappers, or travelers mentioned in the diaries concerning the pristine conditions of the area (fig. 3). Based on a series of assumptions about carrying capacity, range area, habits, and population trends, Seton (1929) estimated a population of from 40 to 60 million bison in North America. Bison were once spread over one-third of the North American Continent with the largest herds distributed along the Mississippi River Valley. During the years previous to disturbance by white man, the total area inhabited by bison was about 3 million square miles (Seton 1929).

Overgrazing by bison, in association with trampling, rubbing, and wallowing, contributed to the creation and maintenance of environmental conditions favorable to a variety of other wildlife (England and Devos 1969). Bison are primarily grazers, so they depended on the herbaceous vegetation for food. Few herbivores possessed the capability for altering the environment as did the bison. These animals require approximately 30 pounds of forage per day, so even large areas could easily be overgrazed.

A dramatic change occurred on the Great Plains during the 1800's. Prior to

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[4]*Mammalian nomenclature from Hall (1965).*

Figure 3.--*The bison or American buffalo was once the dominant animal on the North American central grasslands.*

this time the Indians were completely dependent on bison for their livelihood. Their hunting methods did not cause major changes in bison numbers, and usually resulted in a harvest of surplus animals. It is estimated that approximately 300,000 plains Indians existed primarily by hunting the bison herds between Mexico and Lake Winnipeg and from the Rocky Mountains to the Mississippi River (Allen 1954). The part-Arab horses, escaping from the Spaniards, gave the Indian additional hunting ability. Even with the horse and bow the Indian could not seriously deplete his resource, as the gun and fence was to do later. Liquidation of the bison took about 50 years--by 1883 only a few animals remained.

Pronghorn Antelope

Before intensive settlement of the United States, pronghorn antelope (*Antilocapra americana*) (fig. 4) were the codominant grazing species with bison on the Great Plains and with elk on the Palouse and California Prairies. They were as numerous, if not more so, than the bison (Rand 1945). The present range of pronghorns is more restricted (England and Devos 1969). Most historical writings

Figure 4.--*The present day land-use patterns provide habitat for extensive herds of pronghorn antelope.*

don't refer to excessive slaughter of antelope. Therefore, if antelope were as numerous as estimated, and if they were not slaughtered to the same extent as bison, why did population numbers decrease so greatly?

Perhaps it was due to the reduction in suitable habitat brought about by the extermination of bison and the extensive construction of fences. Perhaps their decline can be attributed to a high susceptibility to disease. Traveling from Fort Abraham Lincoln west to the Little Missouri in 1873, J. A. Allen reported that he saw antelope almost constantly (Bailey 1926). In the interim before his return trip a few months later, a fatal epizootic raged among the pronghorns over most of the area between the Yellowstone and Missouri Rivers and 75 to 90 percent of the pronghorns perished.

Pronghorn antelope populations decreased from an estimated 40 million (Seton 1929) to 13,000 around 1915 (Hoover *et al.* 1959). The species was then afforded rigid protection by landowners and law enforcement agencies, and their current population is estimated at 365,000 (Yoakum 1968). The increase is attributed to: (1) controlled hunting, (2) favorable habitat, and (3) improved wildlife management practices such as transplanting programs, water developments, and fences constructed to permit pronghorn travel.

Pronghorns fill a forage utilization niche that is between the grazers (bison and elk) and the browsers (deer). Pronghorn antelope have adapted well to changes in prairie vegetation resulting from livestock grazing.

When populations of pronghorns and livestock are in adjustment with the forage capacity of a good condition range, competition between cattle and pronghorns is negligible. The compatability of cattle and pronghorn antelope is similar to that which must have existed, in the past, between bison and pronghorn. Competition between domestic sheep and pronghorns can be so severe that the latter will be eliminated. Sheep, which can be kept alive with supplemental feeding, can overgraze the vegetation to a point where it is unable to support pronghorn antelope (Buechner 1960).

Elk

The pristine range of the elk, or wapiti, was as widespread in North America as that of the bison. At least two species of elk inhabited the grasslands and wooded river bottoms: Nelson's elk or wapiti (*Cervus canadensis*), which inhabited the midcontinent grasslands, and the northern Pacific coast grasslands, and the Tule elk (*C. nannodes*), which occupied the Southern Pacific area in the Central Valley of California (McCullough 1969).

The carrying capacity of the Tule elk was estimated at 500,000 animals in pristine time. Several factors contributed to the decline and near extinction of the Tule elk. First, the Spanish settlements of the late 1700's and the invasion of the annual grasses which resulted in the displacement of the dominant bunch grasses, which no doubt had adverse effects upon the Tule elk population (McCullough 1969). Then the increase in competition by wild cattle and horses, the gold rush (1848), and the resulting slaughter of wild animals during the booming market-hunting years, further decimated the population. By 1855, the market-hunting era brought the Tule elk to the end of its time as an important element in the fauna of the region. Today there are about 400 to 500 Tule elk in California's Central Valley (McCullough 1969). The wapiti or Nelson's elk have been completely eliminated over the rest of the grassland habitats they formerly occupied. Their populations are now limited to high mountain ranges.

Deer

The white-tailed deer (*Dama virginiana*) was a frequent part of the hunter's bag during the Lewis and Clark expedition of 1804 to 1806. Mule deer (*Dama hemionus*) shown in figure 5 were less abundant but occurred as far east as Chamberlain, South Dakota (Lewis 1961, Cutright 1969). The Astoria party, which ascended the Missouri in 1811, made no mention of deer while on an overland journey from the mouth of the Cannonball River until they reached the Black Hills of Wyoming (Irving 1868) although they made frequent references to white-tailed deer while traveling along riverways.

Figure 5.--*Mule deer populations increased on the midcontinent grasslands with the control of hunting and the increase in the abundance of woody plants.*

Bailey (1926) reported mule deer to be plentiful throughout North Dakota until about 1880 when their numbers began to decrease as hunting pressure mounted. By 1888 deer were fairly well exterminated from North Dakota because intensive livestock grazing eliminated the shrubby species that provided excellent browse and cover for deer. In the Great Basin and southwest, however, livestock grazing encouraged the invasion of shrubs (Longhurst 1960); thus, deer habitat was often improved. Mackie (1970), in the northern Great Plains, reported that the food and range-use habits of mule deer and cattle differed substantially. Deer ingested primarily shrubs and forbs, cattle mostly grass. Deer inhabited relatively steep slopes, cattle the more open ridgetops and coulee bottoms.

With the disappearance of the bison and elk, the white-tailed deer became the only large herbivore left on the tall grass prairie and savannah. The forest clearing and patch farming practiced by the immigrating settlers increased the edge habitat preferred by the white-tail and this contributed to a substantial increase in the deer population (Severinghaus and Cheatum 1956). On the northern savannah, however, their numbers declined to less than 2,000 in the face of increasing human populations pressures and year-round hunting. The 1930's depression caused farm abandonments resulting in widespread secondary succession, and the restoration of the habitat (Beckwith 1954). By 1968, deer numbers on the northern savannah had increased to an estimated 845,000 (Nixon 1970).

Bighorn Sheep

Before disturbance by the white man, bighorn sheep (*Ovis canadensis*) were numerous in most mountain ranges of the west, and in the "badlands" along portions of the Missouri, Little Missouri, Yellowstone, North Platte, Arkansas, Colorado, Green, and Gila Rivers, and their principal tributaries. They were never characteristic prairie dwellers as sometimes reported, but they did occupy some of the buttes and badlands of the Great Plains region. They were exterminated early in the history of white man settlement. The last Audubon or badlands bighorn sheep (*O. c. auduboni*) was killed in 1916, near the White River of South Dakota (Hipschman 1959).

Small Game

Increased population size of the eastern cottontail rabbit (*Sylvilagus floridanus*) on the savannah and tall grass prairie coincided with the advent and expansion of agriculture (Lord 1963). Its smaller home range makes it more compatible with intensive agriculture (Beckwith 1954). Many miles of brushy fencerows and grassy road ditches adjacent to cultivated fields have furnished good habitats capable of supporting high cottontail populations. The unspecialized habits of the cottontail make it likely to remain an abundant game animal.

The tree squirrel most commonly occurring in the savannah and along river bottoms is the fox squirrel (*Sciurus niger*). It depends on fruits and nuts but also feeds on crops when these are available. One to three squirrels per acre is considered optimum for this type of habitat (Schwartz and Schwartz 1959).

Two lagomorphs inhabit the extensive upland grassland types. The white-tailed jackrabbit (*Lepus townsendii*) on the northern Great Plains and the black-tailed jackrabbit (*Lepus californicus*) on the southern Great Plains. Both depend on good eyesight and speed to avoid enemies because they are not burrowing animals like many other small mammals. Rather, they rest and hide in shallow depressions, or "forms", at the base of a shrub or clump of grass.

Prairie Dogs

The most conspicuous of the grassland rodents were the prairie dogs (*Cynomys* spp.). Prairie dogs were once incredibly numerous. Because prairie dogs eat grass and compete with the livestock industry, their numbers have been reduced by extensive poisoning programs. Dobie (1949) reported information from writers during the late 1800's of prairie dog towns covering 16 million acres with an estimated 400 million animals. These prairie dog towns provide food and/or cover for prairie rattlesnakes (*Crotalus viridis*), burrowing owls, (*Speotyto cunicularia*), and the black-footed ferret (*Mustela nigripes*). The black-footed ferret is completely dependent upon the prairie dog town for both shelter and food. Man's wholesale destruction of the prairie dog has so reduced ferret populations that this handsome weasel is now one of America's rarest

ıammals. Many other wildlife and plant species are associated with the influence of a prairie dog town.

Mammalian Predators

The grassland herbivores originally served as food supplies for a number of mammalian predators. The best known species re the gray wolf (*Canis lupus*), red wolf (*C. rufus*), coyote (*C. latrans*), red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), mountain lion (*Felis concolor*), and bobcat (*Lynx rufus*). The gray wolf depended primarily on the bison and elk for food. Originally they ranged throughout the United States, but now the only remaining populations are in northern Minnesota, Wisconsin, and Michigan (Mech 1966). Loss of prey species and heavy hunting led to the demise of the gray wolf. It had disappeared from the central United States by 1900 (Schwartz and Schwartz 1959).

The fate of the red wolf, which originally ranged from Illinois and Indiana south through the Ozarks and into Texas, was similar to that of the gray wolf. The current status of its population and its distribution is questionable; however, it is generally conceded that the red wolf is restricted in both categories. Thus, it has been placed on the endangered species list by the United States Department of Interior. In the 1940's Leopold and Hall (1945) reported seeing red wolves in the western Ozarks but Pimlott and Joslin (1968) have since reported that the distribution of this wolf currently is limited to the coastal prairie areas.

The coyote is the only canine predator of any significance remaining on the grassland and savannah. Coyotes are continuously subjected to harsh control programs and heavy hunting pressure, yet coyotes continue to expand their range. The coyote prefers a grass-shrub or grass-tree cover combination and its apparent adaptability enables it to rapidly occupy all such areas created by man.

The red fox and gray fox are found in the tall grass and mixed grass prairies. These two species seem to be adapting to the habitat changes caused by current land use.

Depredations by mountain lion on domestic livestock and the resultant control campaign plus habitat destruction led to the virtual elimination of the mountain lion by 1900 (Schwartz and Schwartz 1959). The bobcat has survived, but its range is much more limited (Schwartz and Schwartz 1959). It has also undergone persecution because of the "all-predators-are-bad" philosophy. This legend seems to rest more on fiction than fact because Korschgen (1957a) determined that the bobcat diet is primarily rabbits and squirrels.

The striped skunk (*Mephitis mephitis*), spotted skunk (*Spilogale putorius*), and raccoon (*Procyon lotor*) have survived in close proximity with settlement; and in some cases they live around homesite buildings. Their food supply consists of small mammals, small birds, reptiles, amphibians, insects, and eggs.

Fish

The important fishes occurring in the grassland streams and lakes are the minnows (*Cyprinidae*), the suckers (*Catostomidae*), the catfishes (*Ictaluridae*), the sunfishes (*Centrarchidae*), and the perches (*Percidae*). Members of the sunfish and perch families have been widely introduced into manmade reservoirs and stock-watering ponds. The best known are the large-mouth bass (*Micropterus salmoides*)[5] and the walleye (*Stizostedion vitreum*) (Schultz 1936, Koster 1957, Bailey and Allum 1962, Cross 1967).

Amphibians

Arid climates pose special problems for amphibians. Grassland amphibians have been able to adapt to the arid climates through the evolution of behavioral or physiological traits that tend to conserve moisture. For example, the tiger salamander (*Ambystoma tigrinum*),[6] plains spadefoot (*Scaphiopus bombifrons*), Rocky Mountain toad (*Bufo woodhousei*), and Great Plains toad (*B. cognatus*) are able to escape drying conditions by burrowing. Rapid development of their young enables the spadefoot to use large temporary rain pools for breeding.

The most widely distributed amphibian in the grassland is the leopard frog

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[5] *Fish nomenclature follows Eddy (1957).*

[6] *Amphibian nomenclature follows Conant (1958).*

(*Rana pipiens*), which occurs in some dry habitat but generally within traveling distance of permanent water sources. The bullfrog (*Rana catesbeiana*) is widespread in the central and lower Great Plains and has been widely introduced elsewhere. The bullfrog is aquatic and must have permanent water sources to survive.

Reptiles

Many of the reptiles (turtles, lizards, and snakes) have adapted to arid conditions. The more common turtles include the common snapping turtle (*Chelydra serpentina*),[7] yellow mud turtle (*Kinosternon flavescens*), painted turtle (*Chrysemys picata*), three-toed box turtle (*Terrapene carolina*), ornate box turtle (*T. ornata*), and spiny soft-shelled turtle (*Trionyx spinifer*). Except for the box turtle, all require permanent sources of water.

Most lizards and snakes don't need free water to live. Species found throughout the grasslands include: earless lizards (*Holbrookia* spp.), horned lizards (*Phrynosoma* spp.), spiny lizards (*Sceloporus* spp.), whiptails (*Cnemidophorus* spp.), skinks (*Eumeces* spp.), collared lizards (*Crotaphytus collaris*), hognose snakes (*Heterodon* spp.), coachwhips (*Masticophis* spp.), racers (*Coluber constrictor*), kingsnakes (*Lampropeltis* spp.), black-headed snakes (*Tantilla* spp.), and rattlesnakes (*Crotalus* spp.). Garter snakes (*Thamnophis* spp.) and water snakes (*Natrix* spp.) are found wherever there are streams or lakes (Stebbins 1954, Conant 1958).

HABITAT MANAGEMENT

Despite widespread vegetational changes, the potential value of much of the original grassland areas as rangeland and wildlife habitat remains very good. Some of the associated wildlife species are now absent; populations of others have been reduced, but the majority of species have adjusted to habitat alterations and remain important components in the modern biotic communities. The oak-bluestem savannah, tall grass prairie, and the western bunchgrass types have been most altered by land use practices. The largest grassland type remaining in America is the nearly 200 million acres of midcontinent short grass-mixed grass type. This area supports a large livestock industry and has a large potential for wildlife protection. Livestock management systems are now in operation on private and public lands that strive for multiple use of the grassland with coordinated livestock and wildlife use.

The large number and diversity of wildlife species plus the variability within the grassland plant communities provides for a large number of wildlife habitat management options. These options are further complicated by year-to-year changes in weather and precipitation. Rangeland wildlife and livestock depend on forage production for food and cover. Forage production can vary from nearly nothing on the high plains during droughts to 9,000 pounds per acre (Curtis 1959) on the tall grass prairie. The discussion that follows relates to the food and cover requirements of many of the species previously mentioned. The land manager must use imagination and foresight to design specific systems to provide for an optimum balance of different habitat components.

Wetlands

Many species of wildlife are associated with the natural wetlands and manmade ponds of the grassland areas. Waterfowl and shorebirds are of primary importance. Grassy shorelines support nearly three times as many breeding pairs of ducks as the bare mud type (Linduska 1964). The composition, density, and height of the shoreline vegetation depends largely on the type of grazing system involved. Season-long grazing systems will deplete the shoreline vegetation even if livestock stocking rates are low, unless there are several ponds or watering areas in each pasture. Shoreline vegetation can be maintained by fencing all or part of a stock dam or by using carefully designed rest-rotation grazing systems. Shorelines that are completely protected from livestock trampling and grazing often contain dense emergent vegetation or shrubs that are not suitable for dabbling duck habitat. Management plans should be designed to produce some mudflats for shore bird feeding areas, grassy shoreline areas for duck nesting, and some emergent vegetation growth for duck brood protective cover.

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[7] *Reptile nomenclature follows Stebbins (1954) and Conant (1958).*

Uplands

Brushy cover is to sharptails what grass is to prairie chickens, second growth is to ruffed grouse, and mature coniferous forest is to spruce grouse. On good moisture and soil sites, lack of grazing or rest will bring about an increase in such desirable species as wild plum (*Prunus americana*), chokeberry (*P. virginiana*), silver buffaloberry (*Shepherida argentea*), and hawthorn (*Crataegus* spp.).

Food habits of the sharp-tailed grouse are nearly as variable as the habitats they occupy. Several plant species do occur in most food habits studies, indicating their importance for food and/or cover. These species include dandelion (*Taraxacum officinale*), rose (*Rosa* spp.), hawthorn (*Crataegus* spp.), snowberry (*Symphoricarpos occidentalis*), Russian olive (*Elaeagnus angustifolia*), silver buffaloberry, and buds from *Populus* species. Cultivated crops are eaten when available (Evans 1968). Several of these berry-producing species provide grouse with a winter diet sufficient to survive winter conditions on the northern Great Plains (Hillman and Jackson 1973, Evans and oen 1975).

Evans and Dietz (1974) tested seven iet materials and found nitrogen-corrected etabolizable energy (Kcal/g. dry matter) o range from 3.91 for corn to 1.39 for ose hips. The fruit of silver buffaloberry as the best native winter food item ested. Fleshy hawthorn berries were inested in larger quantity than other airried foods. For maintenance, winter oods needed to be consumed in large enough uantity to provide metabolizable energy in xcess of 1.5 times basal metabolic rate. key to intensive management of winter abitat for sharp-tailed grouse is the ropagation and/or encouragement of high nergy-providing plants. Several native hrub species provide good protective cover or sharptails and produce berries that re palatable and high in energy.

Edminster (1954) listed four types of cover required by the bobwhite: grassland, cropland, brushland, and woodland. he grassland provides nesting and feeding cover during spring and summer. Parmalee (1955) found 85 percent of the nests located during his study to be in grassland. Grassland must be open enough to ermit birds to move about unhampered (Robinson 1957). Dense grassland cover can be opened by using fire, cultivation, or grazing. Croplands provide crop residue and weed seeds which are valuable bobwhite fall and winter foods. Corn (*Zea mays*), Korean lespedeza (*Lespedeza stipulacea*), and sorghum (*Sorghum vulgare*) are cultivated crops which rank high in the bobwhite diet. Ragweeds (*Ambrosia* spp.), wild beans (*Strophostyles* spp.), *Croton* spp., foxtail grasses (*Setaria* spp.), and sunflowers (*Helianthus* spp.) are native annual plants and are prolific seed producers commonly associated with disturbed areas (Baumgartner *et al.* 1952; Korschgen 1952, 1960; Robinson 1957). Insects associated with cultivated crops and forbs are used for food in spring and summer (Rosene 1969). The brushland and woodland areas are used for escape, roosting, and feeding. Casey (1965) questioned the need for tree cover if brushland was available. Robinson (1957) provided support for this idea when he found the number of coveys in an area to be dependent on the number of "headquarter areas", which were brushy cover dense enough to provide adequate protection during periods of high light intensity. Cover type distribution must be planned and incorporated into a total management plan so that access to all cover types will be available within the home ranges of a covey; a home range varies from 12 to 20 acres.

The cottontail rabbit is a close associate of the bobwhite over much of their ranges. The most preferred foods for cottontail rabbits in Missouri, are bluegrass (*Poa pratenses*), wheat (*Triticum aestivum*), and white clover (*Trifolium repens*) (Korschgen, unpublished data). A wide variety of food species appearing in smaller amounts serve to illustrate the catholic taste of the cottontail. Cottontails may become a nuisance if inclement weather forces them to feed on the bark of shrubs, shade trees, orchards, and windbreaks, thus damaging or killing individual plants. Hunting or trapping can be used to effectively control cottontail populations which are exceeding the carrying capacity of the habitat.

Within the various rangeland habitats from sea level to above timberline, many management practices are available for increasing grazing capacity, improving range condition, and creating new range. All are designed to favor livestock. The nongame bird section of most management plans

are short and generally useless for evaluating effects of different practices on birds and their habitats. The interest and awareness of animals other than cattle and sheep is rapidly growing as managers recognize the value of diversified wildlife populations. Buttery and Shields (1975) have summarized information pertaining to bird habitat values and have pointed out research needs.

Big Game

Mule deer, white-tailed deer, and pronghorn antelope currently offer the best potential for big game management. Deer are browsers and require a supply of woody plants for food and cover. Good sharp-tailed grouse habitat on the northern Great Plains is usually compatible with good deer habitat. Some livestock grazing systems are very compatible with deer and grouse populations. Grazing systems that reduce brushy cover in the small drainage areas probably also reduce deer habitat values.

White-tailed deer range can best be described as a mosaic of croplands or pasturelands and oak-hickory woodlots, brushy fencerows, and wooded stream bottoms (Crawford 1970). A survey of deer food habits in Missouri (Murphy 1970) revealed the importance of cultivated crops in the diet, especially corn and soybeans. This survey showed substantial dependence on shrubs and small trees as a food source. Important shrub species are buckbrush (*Symphoricarpos* spp.), sumac (*Rhus* spp.), and hawthorn. Acorns are an important contribution of the tree component in the more heavily wooded areas. Favorable habitat extends along the major drainage across the Great Plains.

Pronghorn antelope differ considerably from deer in their habitat preferences. Deer prefer woody or brushy areas, and antelope prefer upland and open expansions of grasslands. The forb component of grassland vegetation communities is important to pronghorns.

Predator-Prey Relations

Jackrabbits occasionally become so numerous that control campaigns are launched. Because of their size and differences in food habits, it is estimated that approximately 200 jackrabbits are required to remove range forage sufficient to feed 1 cow (Stoddart and Smith 1955).

The coyote often preys on livestock and big game species; however, Korschgen (1957b) reported that the coyote diet in Missouri consisted mainly of rabbits and rodents. This agrees with Murie (1940) who determined that coyotes in Yellowstone consumed primarily rodents and insects. Consumption of livestock or wild mammals other than those mentioned above was 10 percent or less for each. The evidence indicates that often the coyote could be considered a valuable aide in controlling rabbit and rodent populations. In local instances, coyotes can cause economically significant sheep mortality.

In spite of the fox-chicken legend, it appears that the foxes still depend on wild animals for the major portion of their diet (Korschgen 1957a). Rabbits and rodents comprised more than 50 percent of the diet for both species. Foxes have been considered to have both detrimental and beneficial attributes. Detrimental because they occasionally take domestic poultry but beneficial because of the impact they make on rodent populations and the value of the pelt.

DISCUSSION

Past experience indicates that future habitat management objectives are going to require considerable thought and imagination. The bison, elk, and gray wolf are gone from the grasslands and savannahs--victims of changing land use and indiscrimar shootings. Those game species remaining have been able to adapt to changing land use but even these species are limited in the amount of change that they can tolerate. We have hardly considered the multitude of nongame species present. We know that land use changes influence these species (Warbach 1958, Graber and Graber 1963, Buttery and Shields 1975), but insufficient data makes accurate evaluation of these changes difficult. Wildlife has continually been relegated to areas that are difficult to cultivate or to intensively manage, and these areas continue to dwindle as new economic uses are discovered. There are two broad alternatives available to society. The first is to continue managing with a dwindling habitat base usurped by an expanding urban population and intensification of agriculture practices; or secondly, stimulate incorporation of

habitat management practices in land use planning through education and economic incentives.

The land manager must have some incentive for producing wildlife. It is unreasonable to expect a private land manager to voluntarily donate his most productive land to wildlife habitat when the demands of an urban population for farm and ranch products are so great (Crawford 1970). The practice of charging hunters a fee to use private lands is relatively new in many States, but well established in more populated areas. This economic incentive is becoming increasingly popular (Severson and Gartner 1972). Consumptive users have traditionally shouldered the burden of game management costs through license fees and special taxes on hunting equipment. Very little of this money has gone directly to the landowner as an economic return for the wildlife produced on his land. Future wildlife habitat programs will depend on whether or not man is willing to pay a portion of the wildlife productions costs. Adequate procedures for managing wildlife and methods of application are readily available (Wing 1951, Anderson and Compton 1958, Giles 1969, Allen 1972), but widespread application awaits a basic philsophical change in which wildlife will be recognized as an esthetic necessity rather than an esthetic luxury. The fate of wildlife is inexorably linked with the fate of man.

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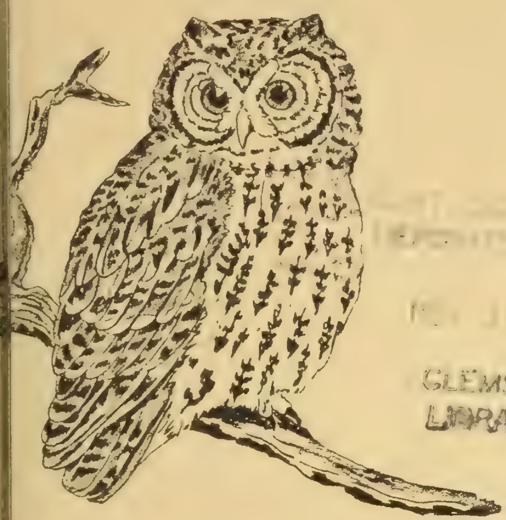

CAVITY NESTING BIRD HABITAT in the oak-hickory forest...a review

BY KIMBERLY I. HARDIN AND KEITH E. EVANS

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CAVITY NESTING BIRD HABITAT IN THE OAK-HICKORY FORESTS--A REVIEW

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The group of bird species referred to s cavity nesters receive both praise and rath from forest managers. The cavity users" rarely cause any conflict with ther forest activities. But cavity makers" are often blamed for reduced eco-omic output from a forest by their exca-ation activities in trees marked for har-est. The criticism is largely unwarranted, owever, because woodpeckers in the oak-ickory forest usually make cavities in rees that previously have been damaged by nsects, disease, fire, or storm.

The 47-million hectare oak-hickory orest is the most extensive timber type in he United States. It extends from the rairie border in Oklahoma northeast through he Appalachian Mountains into the Piedmont nd southern New England. The oak-hickory orest is best developed and most continuous n the Ozark and Ouachita Highlands (Watt t *al.* 1973). High-grading, burning, and razing practices in the past have created tands with a cull volume that ranges from) to 60 percent of the total volume Gingrich 1970). Stands with a cull tree verstory or a high frequency of cull trees reate a unique habitat with abundant nat-ral cavities and many hollow trees suit-ble for cavity excavation. With more in-nsive forestry practices and removal of ll trees by thinning operations or har-est cuts, natural cavities may become mited. Currently, some cavity-nesting pulations are declining, and one, the ory-billed Woodpecker (*Campephilus rincipalis*) of North America is believed be extinct. Most forest management ans do not include steps to improve cav-y nesters habitat. One reason for this that forest managers are unaware of the pe of habitat used by these birds.

The diversity of the 28 cavity-nesting rd species recognized by the USDA Forest Srvice (1973) enhances their value to the frest ecosystem. One aspect of this diver-sty is their size range; from the Turkey Vlture, which has a 180-cm wingspan, to te Carolina Chickadee, which has an 11.5-cm wingspan. Although most cavity nesters are predators, they are highly diversified in the size of their food and the method they obtain it: the American Kestrel feeds on small mammals, large in-sects, and some birds; the owls feed on small nocturnal mammals; the wrens gleen insects from the foliage; and the wood-peckers drill for insects; etc.

Cavity nesters are an important com-ponent of the oak-hickory ecosystem. Nine years of breeding bird survey data in Missouri indicate that cavity nesters make up 22 percent (30) of the 139 species of birds recorded (Evans and Dawson 1976). Frequency data (unpublished, preliminary) showed cavity nesters in the top 10 bird species in all of the 7 vegetation types sampled in Missouri's Ozarks. Forest and forest edge types each included 3 cavity nesters in the top 10 species. Aerial-sprayed areas had 4 cavity nesting species in the top 10. Fescue fields and clearcuts each included one species; these areas were used for feeding.

The purpose of this article is to re-view, analyze, and integrate the published information on habitat selection and util-ization of cavity-nesting birds and relate this information to forest management situ-ations. The report is divided into two major subject areas. First, the known as-pects of the habitat selection and utiliza-tion are covered. This information can be gleened directly from the literature. Second, managment implications are dis-cussed. This information must be inter-preted and adapted from the published in-formation to forest management situations. Some of the potential impacts of managment alternatives are speculative, which are noted with comments on future research needs. One concept appearing, both directly and indirectly, throughout the paper is the concept of species tolerance to habitat variability. The species with inherently narrow tolerances to habitat variability are more vulnerable to forest managment options. Cavity-nesting birds, because

they require cavities to complete their life cycle, are somewhat specific in their habitat selection.

HABITAT SELECTION AND USE

Turkey Vulture--*Cathartes aura*[1]

Turkey Vulture nesting sites are often at a premium because of the large size of the vulture and the shortage of large snags. Because both young and adults eat carrion, the smell around the nest attracts predators. Therefore, a fairly well protected site is required. The birds do not construct their own nests but rely on available sites and will return to the same nesting site year after year unless the site is badly disturbed (Jackson 1903, Kempton 1927). They lay two eggs, usually on whatever litter is present (Bent 1937, Kempton 1927). Inclubating time is approximately 30 days (Jackson 1903).

Turkey Vulture nesting records are fairly numerous. There have been reports of them nesting on cliffs, in caves, in hollow stumps, or in the midst of dense shrubbery with a narrow, easily defendable entrance. The site is almost always near the ground but one was reported to be 6.1 m up in a deep stump and one other 1.8 m below ground level in the hollow of a rotten stump (Bent 1937).

The most frequently reported nesting sites are those located in hollow trees and in hollow logs lying on the ground (Gingrich 1914, Townsend 1914). One nest in a hollow snag had an entrance 4.3 m up but the eggs were laid at ground level (Pearson 1919). Another was found in a live hollow soft maple, which had an inside diameter of 71 cm, was 102 cm above ground, and the opening was 107 cm above the eggs (Kempton 1927). The birds have been reported nesting in caves or dry sink holes in Florida and New York (Howes 1926, Pearson 1919). One nest site in Maryland was on the ground under the overturned bifurcated root stump of a large dead chestnut tree (Williams 1924). There is also a record of a pair nesting on a pig sty (Jackson 1903). Platt (1971) reported that vultures in Curlew Valley, Utah, nested on cliffs for lack of a better place.

[1]*Bird Nomenclature from American Ornithologists' Union (1957, 1973, 1976).*

Black Vulture--*Coragyps atratus*

Black Vultures have some of the same nest site requirements as their close relatives the Turkey Vultures, including the use of available sites that do not require additional construction (Hoxie 1886, Bent 1937). Court (1924) found a Black Vulture nest in Maryland, .6 m below ground level in a large white oak stump. The birds used it for two consecutive years. Another report is a nest with two eggs in an old tobacco shed on an abandoned farmstead in Virginia (Stewart 1974). Hollow stumps or standing trees are favorite nesting sites for Black Vultures. However, the eggs are occasionally merely laid on the ground, often in dense thickets of palmetto, yucca, tall sawgrass, or sometimes in the open, exposed to full daylight (Bent 1937).

The Black Vulture is uncommon throughout most of the oak-hickory type. It is primarily a southern scavenger. The Turkey Vulture inhabits the scavenger niche throughout the northern portions of the oak-hickory forests.

American Kestrel--*Falco sparverius*

Most hawks either build true nests or lay their eggs on open ledges or bare cliffs. However, the American Kestrel (Sparrow Hawk) prefers to lay its eggs in holes, either natural cavities, holes made by other birds, or man-made boxes. In the West, they will occasionally nest in abandoned Black-billed Magpie (*Pica pica*) nests (Richards 1970). Also, in common with other birds of prey, Kestrels require large breeding territories so their nests are widely spaced (Bent 1938).

Smith *et al.* (1972) observed 41 Kestrel nests in Utah. Of these, 28 were located in trees (19 in old flicker holes, 2 in old magpie nests, and 7 in natural cavities). The type and numbers of trees used were: 18 cottonwood, 3 poplar, 3 willow, 2 maple, 1 elm, and 1 apple. Two of the remaining nests were located in the rocky cliffs of abandoned quarries and the last 11 were found on building tops. Nest height ranged from 1.22 m to 19.8 m above the ground. The average height of eggs on buildings was 10 m and the average of the rest of the sites was 6.7 m. There was no observed attempt at nest construction--the eggs were laid either on debris in the cavity or on nest materials of previous occupants. Twelve pair used the same nest site for two consecutive years and eight of these used

same site again the third year. Twenty- pair used the same territory for 2 years 21 returned to the same area the third r (Smith *et al.* 1972).

Roest (1957) found the favorite nest- sites of American Kestrels to be either ndoned Common Flicker holes or natural ities located 2 to 10.7 m above the ound level (tables 1 and 2). Willoughbey Cade (1964) reported that Kestrels pre- an 8 cm hole in man-made boxes. Usually r or five eggs are laid and require ap- ximately 30 days for incubation. Kestrel s are pigmented unlike those of most ity nesters which are white. This sug- ts that Kestrels have only recently, on evolutionary time scale, become cavity ters (Richards 1970).

le 1.--*Nest sites used by American Kestrel (Roest 1957)*
(In number of nests)

	Natural cavity	Flicker hole	Wood-pecker hole	Magpie nest	Hole in cliff	Building	Total
gon	2	6			1	3	12
ginia	1	1					2
York	1						1
ifornia	12	15	3	2			32
ada	1	13	3				17
er	2	2					4
otal	19	37	6	2	1	3	68

le 2.--*Height of American Kestrel nests above the ground (Roest 1957)*
(In number of nests)

ght)	Oregon	Virginia	New York	California	Canada	Totals
-2.7	1				1	2
.25	4			1	8	13
5-5.55	1		1	2	1	5
-7.3	2	1		1	3	7
-8.8	1			2	3	6
-10.4	2			4		6
7-11.9				4	1	5
2-15				4	1	5
2+		1		2		3

Kestrels will often be found on high, osed perches where they can look out wide stretches of grassland or pas- e to watch for prey. Common prey in- les insects, birds, mammals, reptiles, amphibians. Amounts of each vary with season and the locality. They have been observed catching and eating bats nte 1954). During the winter in north- latitudes, prey is restricted to birds small mammals. However, when and where cts are abundant, they comprise the 's principal food. Kestrels are able to overcome birds that are nearly their own size such as starlings. They prefer to hunt in open areas, therefore, natural cavities or nest boxes should be along the edge or ecotone between the forest and an opening (Bent 1938).

Owls

The owls, Order Strigiformes, differ widely in their habitat requirements. Eighteen species of owls live in North America (American Ornithologists' Union 1957), but we will only discuss the habits of the four common cavity nesting, eastern forest owls. They are nocturnal hunters and are rarely seen. Techniques for inventorying the Strigiforme resource have not been developed so the impact management plans have had on owls is not known. Angell (1974), Burton (1973), Hamerstrom (1972), and Sparks and Soper (1970) have all expressed concern for the loss of owl habitat when overmature forests are cut and snags and cull trees removed.

Birds that nest in cavities may accept nest boxes, especially if the box is located near good hunting territory. Owls do not add nest material to their nest site, therefore, it is desirable to put sawdust, hay, or other material in the box so the parent can incubate the eggs without them rolling away. Owls are not known for their architectural selectivity, so nest box design can esthetically and economically please the builder (Hamerstrom 1972). However, different size boxes will attract different species of birds (table 3 and fig. 1).

Table 3.--*Recommended nest box sizes for eastern deciduous forest owls (Hamerstrom 1972)*

Owl species	Floor size	Cavity depth	Entrance diameter	Habitat
	- - - - Centimeters - - - -			
Saw-whet	15x15	20-25	6	Woods and swamps
Screech	20x20	20-25	7.5	Orchards and suburbs
Barred	33x38	38-43	20	Near streams, woods
Barn	33x38	38-43	13	Cities and farmland

Saw-whet Owl--Aegolius acadicus

Saw-whet Owls are small (18 cm), nocturnal hunters of the deep north woods. They do nest as far south as central Missouri, but only rarely. They do winter in Missouri. These small owls prefer to nest in old woodpecker or flicker holes as shown in the following summary of nesting sites used by owls (Bent 1938):

Species	Height above ground (m)	Description
Saw-whet Owl	----	Flicker hole--dead pine stub
	5.5	Flicker hole--dead pine stub
	6.7	Dead maple stump
	12.2	Dead stub
	6.1	Dead stub
	15.2	Dead stub
	19.2	Dead top of maple tree
	7.6	Woodpecker hole--pine stub
Screech Owl	6.1	Flicker hole--dead pine stub
	1.5	Natural cavity--apple tree
	3.0	Natural cavity--apple tree
	----	Flicker hole--dead poplar
	10.7	Natural cavity--large oak
Barred Owl	----	18 times used old hawk nest
	----	15 times used hollow tree
	----	5 times used squirrel nest

Nesting habitat may be improving in areas where Dutch elm disease has infected many elms and woodpeckers have drilled nest holes (Hamerstrom 1972). Pearson (1936) reported they will also use squirrel dens for nesting sites. The mature forest composed of a mixture of trees, living and dead, young and old, is the preferred nesting habitat of Saw-whet Owls (Angell 1974). Their three to six white eggs are deposited on whatever material is found in the cavity.

Saw-whet Owls feed primarily on beetles, grasshoppers, other insects, mice (Hamerstrom 1972), bats, frogs, and small birds (Burton 1973). Winter foods of Saw-whet Owls in Illinois and Iowa consisted of 97 percent mice and shrews of the genera *Peromyscus, Microtus, Cryptotis, Blarina,* and *Mus*. A few birds, mainly Fringillids, were also included (Scott 1938, Graber 1962). Summer foods consist of a high proportion of large insects.

Screech Owl--Otus asio

The male Screech Owl defends a nesting and feeding territory, as do other

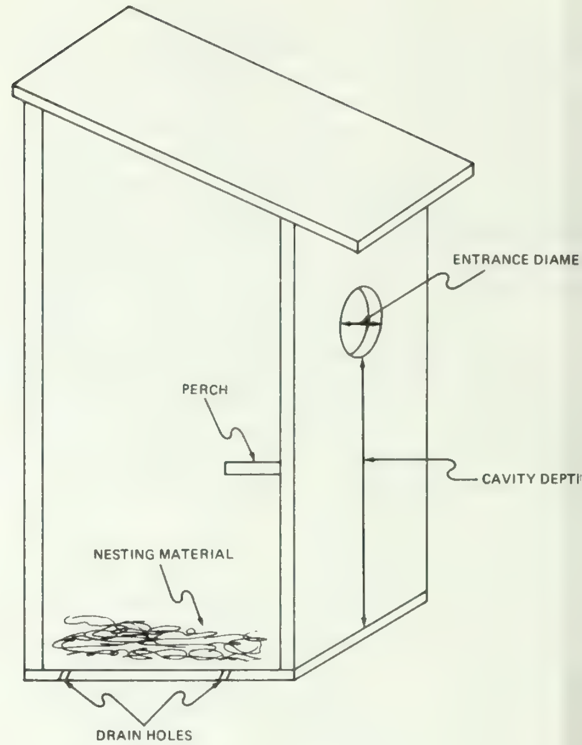

Figure 1.--*Components of an owl nest box.*

owls. Territory size varies and there is usually a neutral zone between individual territories (Burton 1973). Maples, apples and sycamores with natural cavities or pines with woodpecker holes are preferred nesting sites. Old apple orchards seem to provide a good combination of cavities and open hunting areas (Hamerstrom 1972, Bent 1938). Screech Owls lay 5 to 8 nearly spherical, white eggs.

Screech Owls are one of the most nocturnal owls. They do not eat or even hunt until twilight is past. The birds hunt over low-land meadows and fields or catch insects over the tops of trees. Food depends largely on the environment and the most readily available prey. The owl is evidently satisfied with what animal food it can most easily obtain. Foods eaten by Screech Owls in western Missouri based on 419 pellets analyzed from 1957 to 1967 (Korschgen and Stuart 1972) were as follow

Food	Occurrence (Percent)	Volume (Percent)
Meadow mouse	56.6	52.1
White-footed mouse	25.8	18.8
Cotton rat	14.8	14.8
Rabbit	4.8	5.6

ngbirds	8.4	4.1
ort-tailed shrew	3.1	1.8
ast shrew	3.6	1.2
rway rat	0.5	0.5
g lemming	0.2	0.1
use mouse	0.2	0.1
ayfish	0.2	0.1
ne beetles	0.2	Trace
og, unidentified	0.2	Trace

addition to these foods, the owls eat sh, lizards, spiders, earthworms, and rds as large as domestic pigeons, quail, d ruffed grouse. Van Camp and Henry 975) found that Screech Owls on a northern io study area captured 53 species of rds (65 percent of their diet) during e nesting season. They also feed extenvely on insects which they grab off the aves with their talons or catch on-theng in their beaks. Beetles, cutworms, asshoppers, locusts, crickets, cicadas, tydids, and noctuid moths are only a few the many insects that this owl eats ent 1938).

rred Owls--Strix varia

Barred Owls select suitable cavities nesting if available. If natural caves are scarce, they will nest in abandoned tor and squirrel nests. Both the male female are efficient territorial hunters. ir ears are as well developed as their s. Barred Owls can capture a live mouse complete darkness on a bare floor by ible detection. Woodland owls are comly more vocal than open-country owls. red Owls have a unique call that has been cribed as "Who cooks for you, who cooks you-all" (Burton 1973, Sparks and Soper 0).

Barred Owls seem to be diverse in their ing habits and like the Saw-whet and the eech Owls, prey is highly dependent on season. Foods of Barred Owls in west- Missouri based on 700 pellets analyzed m 1949 to 1968 (Korschgen and Stuart 2) were as follows:

Food	*Occurrence* (Percent)	*Volume* (Percent)
dow mouse	26.1	20.2
tontail rabbit	20.1	19.6
ton rat	17.9	17.7
te-footed mouse	32.1	14.4
gbirds	27.0	13.8
yfish	13.6	3.4
h, unidentified	9.1	2.4
e	1.9	1.7
House mouse	2.9	1.1
Short-tailed shrew	2.3	0.8
Harvest mouse	1.4	0.7
Birds, unidentified	1.3	0.7
Grey squirrel	0.6	0.6
Least shrew	3.6	0.6
Frogs, unidentified	4.4	0.5
Snakes, unidentified	1.3	0.4
Grasshoppers	1.0	0.4
Salamander, unidentified	0.6	0.3
Opossum	0.3	0.3
Norway rat	0.1	0.2
Bog lemming	0.3	0.2
June beetles	1.1	0.1
Pine mouse	0.1	0.1
Mourning dove	0.1	0.1

In southern Massachusetts, Barred Owls generally nest in white pine woods (Bent 1938), oak woods, or mixed hardwood-confier types (Nicholls and Warner 1972). The Barred Owl prefers a sparse understory, which facilitates clear flying and attacking prey. Oak woods with many dead or dying trees are preferred because they provide cavities as well as habitat for prey species such as mice and squirrels. Hollow trees also provide perches with good visibility for the owls to hunt from. Because they are nocturnal hunters, owls greatly depend on their hearing to find prey. Perches, which allow the bird to hear rustles in the leaves or scurrying rodents and squirrels, are very important.

Barn Owl--Tyto alba

Barn Owls use a wide variety of nesting sites for their 5 to 7 white eggs (Bent 1938). The sites include natural hollows in trees, holes and cavities in cave banks or cliffs, burrows under ground, sides of old wells, abandoned mining shafts, dovecotes, barns, and church steeples. Several pair have been found roosting in separate cavities of the same tree (Reed 1897).

Barn Owls are distinctly birds of the open country and are less inclined than other owls to shun areas occupied by man. They find their best food supplies in open fields, meadows, and around barns, granaries, and other buildings. In the wild state, birds will hunt as far as 2.4 to 3.7 km from nest site or roost buildings. Adults are almost wholly nocturnal. However, there are a few reports of them leaving roosts and nests before twilight--especially when feeding young (Marti 1974). Territoriality, centered primarily around the nest

site structure, is evident during the breeding season. Overlap of home ranges of adjacent pairs or of a pair and single bird is common (Smith *et al.* 1974).

Studies in Colorado and Pennsylvania found the Meadow Vole (*Microtus pennsylvanicus*) to be the primary food item of the Barn Owl (Smith *et al.* 1974, Reed 1897, Marti 1974). Another study showed House Mice (*Mus musculus*) to be the major item of consumption (Evans and Emlen 1947). Other prey includes members of the genera *Peromyscus, Sorex, Cryptotis, Sylvilagus, Microtus,* and *Rattus* as well as other rodents. Bats are occasionally eaten (Twente 1954, Marti 1974) and birds are also eaten sometimes. Birds such as House Sparrows and Red-winged Blackbirds, which have communal roosts, can become easy targets for Barn Owls. Barn Owls are versatile in their prey habits (Marti 1974).

Pileated Woodpecker--*Dryocopus pileatus*

Forests of dense timber and secondary growth consisting of mixed deciduous trees and conifers are the preferred year around habitat of the pileated woodpecker. Although there are reports of excavating and nesting in live trees, these birds prefer dead trees or dead limbs on live trees. One tree may be used for several years but a previous nest hole is rarely reused. This behavior provides cavities for other wildlife such as ducks, flying squirrels, and owls (Hoyt 1957).

Nests have been found in beech, poplar, birch, oak, hickory, maple, hemlock, pine, ash, elm, and basswood. Height ranged from 5 to 21 m and there was no reported preference of direction for entrance holes (Hoyt 1957). Tall dead trees with bonelike surfaces and few limbs are favored. Nest holes may be up to 10 cm in diameter and as deep as 76 cm (Hoyt 1941). In California, Carringer and Wells (1919) reported several nests in live aspen trees when plenty of dead trees were available. Most of the nests were in trees whose roots were under water. Unlike many birds, Pileated Woodpeckers retain close pair bonds throughout the years. Although the male and female roost in separate cavities, there is usually not much distance between them (Kilham 1974).

Pileated Woodpeckers lead all other woodpeckers in their ability to prey upon certain insects. Ants, especially Carpenter Ants (*Camponotus herculeanus* L.), and beetles are the major insects that comprise 72 percent of their food. Trees with heart rot provide suitable habitat for initial invasion by Carpenter Ants (Sanders 1964). Hence, silvicultural thinnings that remove infected trees could have a critical impact on the Pileated Woodpecker by removing one of its major food items. In the fall, dogwood berries, cherries, beechnuts, acorns, and other wild fruit are included in the bird's diet. Pileated Woodpeckers rely entirely on forests and brushy areas along the forest edge for food (Bent 1939). They are a highly beneficial bird because they stay with one tree until it is rid of insects, which prevents further infection of trees in the vicinity and gives the infected tree a chance to live. People point to dead trees, riddled with woodpecker holes, and blame the death of the tree on the woodpecker. However, the tree probably died from the insect infestation (Hoyt 1957).

During the regeneration stage of even-aged timber management systems, stands have little potential for Pileated Woodpecker nesting. These woodpeckers prefer older-aged stands that offer trees large enough for nesting cavities (table 4). Timber stands with medium size sawtimber (38 to 46 cm d.b.h.) would provide adequate Pileated Woodpecker nesting habitat if some of the trees were decayed (Conner *et al.* 1975).

Red-Headed Woodpecker--*Melanerpes erythrocephalus*

As with the other woodpeckers, cavities are important to Red-headed Woodpeckers all year, not just during the nesting season. Trunks of dead trees are the favored location for nesting cavities (table 5). Entrances of excavated holes usually face to the south or west (Reller 1972).

Red-headed Woodpeckers eat a wide variety of food depending on availability. Insects, including ants, wasps, beetles, bugs, grasshoppers, crickets, moths, and caterpillars, are the main year-around food. Fruit provides a supplement to their diet and they have been observed eating corn, dogwood berries, huckleberries, strawberries, blackberries, elderberries, wild black cherries, wild grapes, apples, pears, various seeds, acorns, and beechnuts.

Table 4.--*Average measurements of woodpecker nest trees in forest habitats in Virginia (Conner et al. 1975) (ranges are given in parentheses)*

Measurement	Species			
	Downy	Hairy	Flicker	Pileated
Male bird length (cm)	14.5	19.0	26.5	38.0
Nests (No.)	15	10	6	14
Nest tree dbh (cm)	31.8 (15-66)	40.6 (20-64)	36.8 (30-46)	54.6 (33-91)
Nest tree cavity diameter (cm)	20.8 (13-41)	25.2 (20-46)	27.9 (23-36)	37.9 (30-51)
Nest tree height (m)	8.3 (1.5-19.8)	13.0 (4.0-26.5)	12.4 (9.1-15.8)	20.3 (10.7-36.6)
Nest height (m)	4.7 (1.0-11.6)	8.8 (2.4-19.8)	8.5 (6.1-11.9)	13.6 (9.1-19.2)

able 5.--*Nest site preference of Red-bellied and Red-headed Woodpeckers (Reller 1972)*

Species	Height (m)	Entrance hole direction	Tree type	Portion
Red-headed	12	SW	Dead	Trunk
	10	NW	do	do
	7	WSW	do	do
	7	NE	do	do
	15	WSW	do	do
	12	SE	do	do
	12	SW	do	do
	12	SE	do	do
	20	S	do	do
	17	SW	do	do
Red-bellied	13	SW	*Quercus rubra*	Limb
	13	W	Dead maple	Trunk
	10	S	*Quercus velutina*	Dead limb
	22	NW	*Plantanus occidentalis*	do
	20	WSW	*Quercus velutina*	do
	10	S	*Tilia americana*	do
	12	E	*T. americana*	do

casionally, this woodpecker eats eggs small birds or kills and eats young rds and rodents (Bent 1939).

In the winter, Red-headed Woodpeckers ost and live in small well-defined terri-ries (Kilham 1958a, 1958c). Pin Oak *ercus palustris*) acorns comprise a rge portion of the winter food. The odpecker stores the nuts whole or in eces in cracks and crevices in bark and so in cavities that are sealed with bits bark when filled. These birds also ore insects in sealed hollows of trees lham 1958b).

Red-headed Woodpeckers prefer to nest roost near open areas. Fields, edges, sprayed timber with little or no high f canopy are highly favored habitats. of their activities--feeding, nesting, roosting--are carried out in mature tim-stands. They are attracted to forest areas that have been sprayed with herbicide and contain many dead snags and lush herbaceous ground cover. Concentration of Red-headed Woodpeckers in sprayed areas is often spectacular.

Red-Bellied Woodpecker--*Melanerpes carolinus*

Red-bellied Woodpeckers often excavate their cavities in dead limbs of live trees (Reller 1972), unlike the Red-headed Woodpecker which prefers to nest in dead trees. Reported nesting sites for Red-bellied Woodpeckers include one 6 m above ground in the dead stub of a living ash, one 18 m up on a dead elm, and another 6 m up in the dead top of a living willow (Kilham 1961) (table 5). From September to January the male and female roost in separate cavities. One of the roost cavities becomes the nest site (Kilham 1958a). Cavities are usually excavated in mature timber stands where the bird's activities are centered. Loveless (1975) found Red-bellied Woodpeckers commonly using the forest edges of central Missouri. The Red-bellied Woodpecker ranked 12th on the list of 49 bird species using edge plots.

Red-bellied Woodpeckers consume more vegetable matter than do most woodpeckers. Vegetation eaten includes corn, acorns, beechnuts, pine seeds, juniper seeds, wild grapes, blackberries, strawberries, pokeberries, cherries, apples, mulberries, elderberries, blueberries, and fruit from Virginia creeper, holly, dogwood, and poison ivy. Seeds from ragweed, wild sarsaparilla, hazelnuts, and pecans are also eaten. These birds cause some economic damage by sucking pulp from oranges in the South (Bent 1939). But the insects eaten--including ants, adult and larval beetles, and caterpillars--more than atone for the damage (Bent 1939).

Red-bellied Woodpeckers store food in the fall by hammering acorns of various kinds into pieces and storing them in cavities. Berries are stored in rootlets of vines as well as in cavities. Knowledge of the presence of these stores is retained and reinforced by the bird's habit of occasionally restoring his supplies (Kilham 1963). In the winter, these woodpeckers are easily attracted to artificial feeding stations, especially those offering suet, nuts, or breadcrumbs.

Common Flicker--*Colaptes auratus*

Lawrence (1967) reported that Flickers prefer to nest close to the top of dead stubs. When excavating their own nest sites, Flickers seem to prefer trunks with smooth, open surfaces (table 6). Entrance direction shows a preference for the south and east, perhaps to ensure the access of light and warmth into the cavity when nesting (table 7). Flickers often excavate in the same tree year after year. They may also use excavations of other birds such as Pileated Woodpeckers (Lawrence 1967). Lawrence (1967) measured the height of 25 Flicker nests and found a range of 2.5 to 14 m with an average of 7 m. Observations reported by others support Lawrence's statements. One Flicker nest was found 3 m above the ground in a rotten maple stump which also had a Downy Woodpecker and a Bluebird nest (Brewster 1893). In New Hampshire, Kilham (1959) reported two nests in dead pine stubs, one of which was 15 m above ground. Concentrations of 19 breeding pairs per 40 ha of white pine forest have been observed in Massachusetts (Dennis 1969).

Table 6.--*Woodpeckers' selection of tree species for nest sites (Lawrence 1967)*

Tree	Flicker		Hairy		Downy	
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*
In live trees	6	24	10	91	0	0
In dead trees	19	76	1	9	11	100
In trees used before	15	60	2	18	5	45
In *Populus tremuloides*	19	76	11	100	11	100
In *P. grandidentata*	2	[illegible]	0	0	0	0
In other trees	4	16	0	0	0	0
Total nests	[1]25		11		11	

[1]Totals do not add up as categories are not mutually exclusive.

Table 7.--*Orientation of the nest openings (Lawrence 1967)*

Species	N	NE	E	SE	S	SW	W	NW	Total
Flicker	2	1	5	8	8	0	0	1	25
Hairy	0	1	4	1	2	0	2	1	11
Downy	0	0	2	2	2	2	3	0	11
Total	4	2	19	17	27	4	13	3	89

Flickers seem to prefer open country or lightly wooded areas although occasional nestings in deep woods have been reported. They nest in suburban areas where trees and parklike areas are plentiful as well as in rural districts. In fall and winter, Flickers live in open woodlands, fields, or meadows, and occasionally coniferous woods or swamps (Bent 1939).

Sixty percent of a Flicker's food intake is animal matter. Of this portion, 75 percent is ants (they eat more ants than any other bird). The rest of their insect intake includes beetles, wasps, grasshoppers, crickets, mole crickets, cinch bugs, wood lice, caterpillars, grubs, and various flying insects. The vegetable portion of their diet is similar to the vegetable portion of the diets of the Red-headed and Red-bellied Woodpecker except that no mast and few cultivated crops are consumed (Bent 1939).

Conner *et al.* (1975) reported most Flicker nest trees were in edge habitats such as woodlots and suburban areas, and the only nest trees found in forest areas were in clearcuts. Flickers frequently feed on or near the ground in open habitats. Selecting a nest tree with open ground availability appears to be equally important to selecting a suitable tree. The parklike habitat selection is illustrated by Loveless (1975) who reported a significantly high frequency of Flickers on forest-grazed pasture edges compared to forest-old field edges. Livestock grazing apparently eliminates some of the lush herbaceous cover and makes the area more suitable for ground feeding.

Hairy Woodpecker--*Picoides villosus*

Hard-centered live trees located in open woodlands were the most commonly used nesting site of Hairy Woodpeckers observed by Lawrence (1967) (table 6). Kilham (1968a), however, found many birds nesting in living trees with rotten centers. Lawrence (1967) measured the height of 11 nests and found a range of 4.5 to 14 m with an average of 10.5 m. D.b.h. of 7 of the trees used for nesting ranged between 25.5 to 35 cm with an average of 28 cm. The size of a Hairy Woodpecker's nest entrance is very convenient for starlings and flying squirrels (Kilham 1968a). Often Hairies will excavate their cavity with the entrance camouflaged or hidden, such as on the underside of a limb (Lawrence 1967). Nests have been reported

4 m up in the rotten center of an aspen, within the rotten center of a living butternut located between two fields, and 7 m up in a living white birch in an open forest composed of red oak, birch, and hornbeam (Kilham 1968a). Common Flickers and Downy Woodpeckers nest primarily in dead trees, but Hairy Woodpeckers use living trees. If the woodland where the woodpeckers nest have few suitable nest trees, the birds may be forced to excavate holes in nest trees that are below optimum size (table 4) or too rotten to be safe.

Hairy Woodpeckers make an effort to prevent competition for food as shown by the following general differences in the foraging behavior of males and females (Kilham 1968a):

	Male	*Female*
Area	Away from nest	Close to nest
Foraging	Mostly in trees	Trees, bushes, ground
Location of prey	Deep in wood	Superficial
Size of prey	Large	Small
Hunting technique	Deliberate	Keeps moving
Visits to young	Few	3 to 4 x no. of male
Care of young	Less concern	More attentive

Male Hairies were observed excavating dead trunks or limbs of aspens, black cherries, red oaks, and maples. These trees occurred mainly either along stone walls and dirt roadways, which had protected them from lumbering, or in fairly mature woods. When both members of a pair were feeding together, the female would usually feed on insects in dying elms by the roadway or on white and yellow birches in the woods (Kilham 1965). Both sexes supplement their primarily insect diet with fruit, some corn, and mast consisting of acorns, hazelnuts, and beechnuts. They will also eat suet and fat from carcasses in the winter. Hairies have been accused of sucking sap, however, this is not substantiated. Any sap or cambium taken is probably incidental to searching for insects (Bent 1939).

Downy Woodpecker--*Picoides pubescens*

Downy Woodpeckers resemble Flickers in many of their nesting habits (tables 4 and 6). Like Flickers, Downies prefer to excavate near the top of dead trees in fairly open timber stands. They will often make new excavations year after year in the same tree. They do not use cavities of other birds because they prefer to make a hole to suit their own tastes (Lawrence 1967). In the fall, each bird excavates a fresh hole to use as a winter roost (Kilham 1962). Lawrence (1967) measured the height of Downy Woodpeckers' nests and found a range of 4 to 15 m with an average of 9 m. D.b.h. of four trees used for nesting ranged from 21 to 30 cm with an average of 26 cm.

Insects comprise the main portion of the summer diet of Downy Woodpeckers. In Lyme, New Hampshire, *Xylococculus betulae*, an insect found in large numbers on paper birches and sometimes on yellow birches and beech, is an important food most of the year. The birds probably are responsible for keeping the insect population under control (Kilham 1970). Elsewhere, beetles, weevils, ants, and caterpillars comprise more than 60 percent of their diet. Other insects and wild fruit make up the remainder of their food (Bent 1939).

Downy Woodpeckers often feed on low vegetation. The distribution of Downies in one study was highly correlated with sapling density. Therefore, sustained brush clearance in the forest would decrease the amount of Downy Woodpecker habitat (Shugart *et al.* 1974).

Red-breasted Nuthatch--*Sitta canadensis*

Red-breasted Nuthatches will excavate their own cavity if a suitable cavity is not available. The female chooses the nesting site and does most of the excavating. After excavation, a true nest is built in the hole. Nuthatch nests have been found in old poplar and yellow birch snags (de Kiriline 1952, Kilham 1973).

Red-breasted Nuthatches breed in Canada and northern Minnesota, Michigan, and northern New England where they prefer evergreen forests (Peterson 1964). The bird is only a winter resident of Missouri. Nothing specific was found about the winter habitat but this Nuthatch probably roosts in natural or previously made cavities during the winter. Seeds of pine, spruce, and fir are its main winter diet with insects included when they are available. Nuthatches will use bird feeders offering suet (Bent 1948).

White-breasted Nuthatch--*Sitta carolinensis*

White-breasted Nuthatches nest almost exclusively in natural cavities within living trees of mature forests (Kilham 1968b). When there are absolutely none to be found, they may use an abandoned woodpecker hole (Pearson 1936). No reports in the literature were found of any White-breasted Nuthatches excavating their own nest hole. However, E. L. Bull observed a pair nesting in a cavity they had excavated in a grand fir (*Abies grandis*).[2]

Because they are natural cavity nesters, these nuthatches compete fiercely with tree squirrels for cavities. Kilham (1968b) found that squirrels are attracted to two sizes of entrance holes in old sugar maples, holes of 3 to 4 cm in diameter attract red squirrels (*Tamiasciurus hudsonicus*) and holes of 7 to 10 cm in diameter attract grey squirrels (*Sciurus carolinensis*). Two reports of red squirrels occupying cavities used the previous year by White-breasted Nuthatches were discovered. Kilham (1968b) found that flying squirrels (*Glaucomys* spp.) do not compete with nuthatches for cavities because they seem to prefer woodpecker holes rather than the natural cavities used by White-breasted Nuthatches (Kilham 1968b).

Like Kestrels, White-breasted Nuthatches lay spotted eggs. This indicates, according to Haartman's (1957) classification, that the birds are secondary hole nesters and have acquired cavity-nesting habits much more recently than such species as woodpeckers, which lay white eggs (Kilham 1968b).

A myriad of insects, including larvae of the gypsy moth and the forest tent caterpillar, beetles, spiders, caterpillars, and ants comprise the main diet of White-breasted Nuthatches throughout the spring and summer. The winter diet is composed of beechnuts, acorns, hickory nuts, maize, and sunflower seeds. They can be attracted to feeders offering suet and sunflower seeds (Bent 1948).

Carolina Wren--*Thryothorus ludovicianus*

Carolina Wrens are versatile in their nesting site choices. Their nests have sides, a roof, and a side entrance, and are made predominantly from dry leaves, stems, and leaf skeletons. They prefer to build on a ledge or some kind of receptacle to give their nest support. They are well adapted to the habitats of man but also nest in the woods there they prefer tangles and brushy undergrowth (Laskey 1948, Peterson 1964).

Animal food, which is nearly all insects, makes up 94 percent of the Carolina Wren's diet. Of this, beetles, caterpillars, moths, and various Hemiptera and Orthoptera comprise the largest portion. The 6 percent vegetable matter is consumed during the winter when insects are unavailable. The chief component of the vegetable part is seeds including those of bayberry, sweet gum, poison ivy, sumac, pine, and acorns. Carolina Wrens come freely to feeding stations placed near brush piles, thickets, or other shelter to feed on ground peanuts, suet, bone marrow, or hamburger (Bent 1948).

Laskey (1948) reported that of the 37 Carolina Wren nests found; 17 were in bird boxes, either stationary or swinging; 9 were on shelves or various ledges inside a building; 4 were among growing plants in window boxes; 2 were in sacks of old clothes in a hen coop; and the remainder were in various other places such as a tin newspaper cylinder and a mail box. There are other reports of different locations for Carolina Wren nest sites. Among these are two accounts of the bird nesting in old hornet nests (Brooks 1932), and a pair that nested in a grape basket covered with a shingle (Nice and Thomas 1948). From the literature, it seems Carolina Wrens prefer a fairly well enclosed nesting site. However, they are not totally dependent upon cavities.

Bewick's Wren--*Thryomanes bewickii*

Nests of the Bewick's Wren can be found in a multitude of places. They are usually located in cavities in or within a few feet of the ground. Most nests are cup-shaped and open above, but occasionally the wren will build a dome over the nest if there is not enough cover present. Nests have been found in rock walls, piles of boxes, under tile on a roof, and in man-made nesting boxes when secluded enough. Two nests were found in natural cavities in fallen trees in the forest and one was found in a rotted-out cavity 3 m above ground in a live oak. Another interesting nesting site was a hole 15 cm wide and 10 cm deep

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[2]*Bull, Evelyn L. 1976. Personal communication.*

hat extended horizontally back 45 cm into
hillside (Miller 1941). There is also
report of a pair of wrens nesting in the
love compartment of a truck in an open
arage (Beemer 1947).

Here again is a case of high adapt-
bility in choosing a nesting site. From
he literature, it would seem Bewick's Wrens
re capable of adjusting themselves to suit
heir environment much better than some
irds.

Bewick's Wrens, like other wrens, can
e useful to have around because of their
arge consumption of insects; insects make
p 97 percent of their diet. In the South,
ewick's Wrens eat boll weevils and in
ebraska they consume locusts (Bent 1948).

House Wren--*Troglodytes aedon*

Like the Bewick's Wren and the Carolina
ren, the House Wren is generally catholic
n its choice of a nesting site. Odum and
ohnston (1951) found three House Wren nests
n pipes less that 5 cm in diameter that
ere used as slanting braces for a fence.
hen it can find them, the House Wren pre-
ers cavities in trees or nesting boxes.
arolina Wrens and House Wrens are aggressive
n their nesting habits and will drive
ther birds from cavities. They will nest
n the vicinity of each other but the more
imid Bewick's Wren does not nest very
uccessfully in the presence of Carolina
r House Wrens (Sutton 1930).

House Wrens eat large quantities of
nsects and arthropods. Their diet is
imilar to that of the wrens already men-
ioned (Bent 1948).

Great Crested Flycatcher--*Myiarchus crinitus*

The Great Crested Flycatcher is unable
o excavate a cavity, so it must use
atural cavities or excavations made by
ther birds. Nests have been found in oak,
sh, maple, birch, pine, cedar, chestnut,
ulip, pear, tupelo, sycamore, and locust
rees. Most nests occur below 6 m, but
hey have been found from 1 to 21 m above
he ground. The bird prefers a large cav-
ty, which averages 45 to 76 cm deep, for
ts bulky nest and likes a hole large enough
or easy access. They seem to prefer nat-
ral cavities--even deep ones that they
ill with trash to within 30 to 45 cm of
he top before constructing a nest (Bent
942).

Great Crested Flycatchers' food consists of 94 percent animal and 6 percent vegetable material. Members of the family Lepidoptera were eaten most frequently, followed by various Coleoptera, Orthoptera (mainly grasshoppers, crickets, and katydids), then Hymenoptera (including many sawflies). Although the bird is called a flycatcher, very few true Diptera are eaten. Most food is taken on wing in the usual flycatcher fashion. However, in the early spring, much food is taken on or near the ground or from crevices in tree bark. Vegetables eaten are mainly wild fruits--including mulberries, pokeberries, sassafras, spicebush, raspberries, chokecherries, Virginia creeper, wild grapes, huckleberries, blueberries, and elderberries (Bent 1942).

Great Crested Flycatchers were originally a deep forest bird. However, with clearing on much forest land and thinning being carried out on a lot of the remaining forest, flycatchers find fewer cavities in which to build nests. They have learned to adapt to living in more open situations, such as old orchards, isolated trees in open lots, and around human habitations. Nesting in forests is still done when cavities can be found, but flycatchers now inhabitat the less extensively and less densely forested areas, becoming more of a forest edge species (Bent 1942, Loveless 1975). Hespenheide (1971) found the birds breeding in a wide range of habitats and coexisting with never more than one species of smaller flycatcher. Aspects of habitat utilization by coexisting flycatchers to avoid competition are not known.

Tree Swallow--*Iridoprocne bicolor*

Before North America was settled, Tree Swallows built nests in hollow trees or deserted woodpecker cavities. Occasional nests are located in old apple orchards and in holes of trees in or near meadows (Bent 1942). They can also be found nesting in old woodpecker holes if many dead trees are standing close to or in water (Whittle 1926). Houses erected for Purple Martins serve as nesting sites if old trees are felled and woodpecker holes are usurped by other cavity nesters.

Some authors consider Tree Swallows to be colonial and others with similar data say they are not. They are not as colonial as Purple Martins and are jealously watchful and pugnacious toward all birds of similar

nesting habits, including other Tree Swallows (Norton 1917). Reports have been made of many pairs of Tree Swallows nesting in multi-compartmented Martin houses. However, most of these have been discounted as incorrect observations. Multi-compartmented houses may be filled before the June breeding season but as soon as the nesting urge is felt, one pair takes over the entire house and allows no other bird to nest there (Whittle 1926). Whittle (1926) considers them to be colonial because of nesting densities which can be attained. By posting houses at least 2 m apart, birds can be concentrated in numbers of up to 150 pair per 0.3 ha. Factors that limit this density are the amount of open area for nesting boxes and adequate feeding areas such as meadows, marshes, or water.

Low (1933) gives dimensions of two boxes used commonly for Tree Swallows. The first is the Packard Bluebird box which is 12.7 by 12.7 cm on the bottom, 23 by 12.7 cm on the back, 19 by 12.7 on the front, and 19 cm square on the top. The Higgins box is 23 cm deep, 15.2 cm long, 14 cm wide, and has a flat top that overhangs the front by 5 cm. Both boxes have entrance holes 3.8 cm in diameter. It is recommended they be mounted on 1.7 m posts in open fields.

The Tree Swallow is the first of its tribe to arrive in the North in the spring and the last to depart in the fall. They can subsist on seeds and berries and therefore, are not so closely confined to insect abundance as are other swallows. Tree Swallows are partial to waxmyrtle and bayberry in the limited zones where they grow. Proportions of plants in their diet were 30 percent in the winter, 1 percent in the spring, 21 percent in the summer, and 29 percent in the fall (Martin *et al.* 1951, Forbush 1955).

Purple Martin--*Progne subis*

Before white man settled North America, Purple Martins built nests in natural cavities or in cliffs (Bent 1942), or in abandoned woodpecker holes in trees (Allen and Nice 1952). A few also nested in bird houses built by the Indians out of gourds. Purple Martins probably never did inhabit the great forests of the East but were found mostly on open grassy valleys, along rivers, around lake shores, and by seacoast marshes (Forbush and May 1955). Today, houses are set up for these colonial birds on poles in open areas with separate apartments that house from 1 to 200 birds (Bent 1942).

A Purple Martin house can be built to any size, but each apartment in it should be 15 by 19 by 13 cm high. The entrance hole is 6 cm in diameter. The house, painted white so as not to disturb the birds and provide a cooler nesting area (Sawyer 1955), is placed on a pole or roof 4 to 6 m from the ground.

Purple Martins are one of the first birds to arrive in the spring. The males arrive before the females and establish themselves at the nesting boxes. The Purple Martin has a strong homing instinct and will remember where old nesting boxes were the year before even if the boxes have not been put up for that year yet. The Martin house should not be erected or the entrances should be closed off until the birds arrive. Otherwise English Sparrows and Starlings will take over and the Purple Martins probably won't nest successfully (Bent 1942).

The Purple Martins' diet consists solely of insects. These are procurred mostly on-the-wing in the typical swallow fashion by darting, swooping, and skimming pond surfaces. The Purple Martin normally flys at a moderate speed but its favorite food, the fast flying dragonfly, is easily caught. The Purple Martins' diet is made up primarily of ants, wasps, flies, dragonflies, and a few bees. This bird is beneficial to man because it consumes millions of mosquitoes and houseflies (Allen and Nice 1952). Some birds will feed on the ground especially in severe weather when they can pick up dead or stunned insects (Forbush and May 1955).

The Purple Martin is an early fall migrant. They gather in large numbers to migrate (Bent 1942) to their winter home in Brazil (Pearson 1936).

Black-capped and Carolina Chickadees--*Parus atricapillus* and *Parus carolinensis*

Carolina and Black-capped Chickadees have similar nesting habits and are both found in Missouri. The Wildlife Habitat Management Guide for the National Forests in Missouri (1973) mentions only the Carolina Chickadee, which is the common nester south of the Missouri River on the National Forest lands. Black-capped Chickadees nest north of the Missouri River.

Until the breeding season, Chickadees roost anywhere it is convenient and generally not in cavities (Odum 1942). When the nesting season approaches, several nest sites are searched out and inspected. Often a pair nesting for the second year will nest in the cavity they used the previous year after making some alterations (Brewer 1961). The birds are found nesting in comparatively open situations such as young forests, hedgerows, or field borders. However, these sites are near deeper woods where Chickadees generally feed and rest (Odum 1941a).

Brewer (1961), working in Illinois with a population of Carolina Chickadees, a population of Black-capped Chickadees, and a population of the two species that had interbred (called the Vandalia population), found common likes as far as nesting stubs were concerned (table 8). Nests were found in cavities of stubs usually 1.6 to 2 m tall and 11 to 13 cm in diameter. Trees with partially decayed cores and firm shells were preferred. The particular tree species favored depends on the region. The 18 nests observed by Odum (1941b) were found in the following tree species: 4 in pin cherry (*Prunus penslyvanica*), 3 in paper birch (*Betula papyrifera*), 3 in beech (*Fagus grandifolia*), 2 in yellow birch (*Betula lutea*), 2 in willow (*Salix bebbiana*), 1 in basswood (*Tilia americana*), 1 in sugar maple (*Acer saccharum*), 1 in white ash (*Fraxinus americana*), and 1 in an apple tree.

The most suitable nesting sites are soft trees such as birch and pin cherry. These trees occur as living trees in the early seral stages but are short-lived and persist in the intermediate seral stages as decayed snags. By the time the mature forest develops, all are gone and the dead timber is mostly harder wood, less suitable for excavation. Occupancy of cavities other than those excavated by themselves is rare among Chickadees. If they do use an existing cavity, they almost always do some excavating in it. They will nest in boxes where some excavation is possible. This would mean partially filling boxes with peat and sawdust to entice Chickadees to use them (Brewer 1961).

Food of both Chickadee species are similar; approximately 70 percent animal matter and 30 percent vegetable matter. Vegetable intake is mostly wild fruits such as bayberries, blackberries, blueberries, poison ivy berries, and a little mast. Caterpillars, eggs, and full-grown moths are the insect items most often ingested. Spiders come next, then beetles, true bugs, ants, and various Hymenoptera and Orthoptera. Even in the winter, insects comprise more than half of their food; largely eggs of moths, katydids, and spiders. Bud and bud scales, which are ingested while eating plant lice, comprise less than 25 percent of the winter diet. Birds can be lured into feeders that offer bones with bits of raw meat and gristle attached, cheese, suet, sunflower seeds, and breadcrumbs (Bent 1946, Martin *et al.* 1951).

Tufted Titmouse--*Parus bicolor*

These active birds are generally found in groups of two to six in thick growth and often near water. They are essentially nonmigratory and although they are conspicuous in late fall and winter, they tend to disappear in late spring in order to nest and molt (Gillespie 1930). Many authors state Tufted Titmice nests are difficult to locate. Brackbill (1970) and Middleton (1949) both have reported observing titmice nests but these were in nesting boxes. Laskey (1957) observed nests in natural cavities that averaged from 1.5 to 2 m above ground--extremes were one that was 0.45 m above ground in a gum tree and one that was 6 m above ground in a hackberry. The female constructs a nest made of green moss, grass, leaves, vegetal matter, an occasional snake skin and lined with soft fiber or hair in which to lay her 5 to 7 eggs (Laskey 1957).

Table 8.--*Dimensions of nesting cavities of Black-capped and Carolina Chickadees and Chickadees of the Vandalia population (Brewer 1961)*

Measurement	Carolina Chickadee		Blk-capped Chickadee		Vandalia Pop.	
	No.	Mean ± S.E.	No.	Mean ± S.E.	No.	Mean ± S.E.
		mm		*mm*		*mm*
Entrance hole diameter						
Vertical	3	40.2±0.1	3	47.3±.4	5	42.0±1.4
Horizontal	3	44.7±5.4	3	41.4±2.7	6	36.7±1.6
Cavity diameter	2	65.2	4	64.8±3.4	2	81.8
Cavity depth	3	179.0±18.0	4	199.0±9.0	4	221.0±20.2

In the fall, Tufted Titmice abandon carefully guarded breeding territories and form small groups. There is some argument as to whether they have definite, more expanded winter territories or whether they are rovers (Condee 1970). Van Tyne (1948) offers a solution in her observation that in Michigan there seem to be titmice with restricted home ranges (assumed to be full adults) and those that wander (assumed to be birds in first winter).

The diet of Tufted Titmice also changes from season to season. In spring and summer it is mainly an animal diet (89 percent and 82 percent, respectively). Caterpillars often make up more than 50 percent of animal material (Martin *et al.* 1951) so the birds spend most of their time in the treetops. During late fall and winter, their diet is mainly vegetable (78 percent). Common winter foods consist of beechnuts, acorns, dogwood, Virginia creeper berries, alder seeds, Japanese honeysuckle, and seeds of tulip-tree pods so during the winter the birds spend more time on or near the ground (Gillespie 1930).

Eastern Bluebird--*Sialia sialis*

Bluebirds prefer to nest in natural cavities in savanna-like habitats consisting of pasture areas with scattered small trees and bushes near lakes (Rustad 1972). Nests are neatly made of dry grass or other plant material. The female lays from 3 to 6 eggs, which are most often blue but occasionally are white. In a good season, the female can raise three broods (Zeleny 1973).

Presently, Eastern Bluebird populations are low throughout most of their range because of a serious shortage of acceptable nesting sites, and because of competition from other, more aggressive birds. The birds refuse to nest in dense woods. In the more open areas, which they prefer, people often remove dead trees and limbs because they are unsightly or inconvenient when cultivating. Wooden fence posts are slowly being replaced by metal ones. Thus, these potential nest sites are disappearing (Pinkowski 1976, Zeleny 1973). Competition for nest sites has always been present but now is more intense because the number of suitable sites is diminishing. Tree Swallows, House Sparrows, and House Wrens all compete, usually successfully, with Bluebirds for nest sites (Rustad 1972, Musselman 1935).

Competition for nest sites has forced the Eastern Bluebird away from human population centers where Starling and House Sparrow densities are high. Clearcuts in mature oak-hickory forests create a suitable nesting habitat for Bluebirds--seven of 10 clearcuts searched contained an active Bluebird nest. All seven nests were in standing dead snags, and often were constructed in abandoned Common Flicker excavations. Entrances to the nest cavity ranged from 4 to 12 cm in diameter. If dead snags are left standing, clearcutting can create an acceptable nesting habitat for Bluebirds for at least 12 years afterward. Starlings and House Sparrows are usually absent from clearcuts (Conner and Adkisson 1974).

Pinkowski (1976), reporting on 98 cavities used by Bluebirds, found that 78 percent of the nests were in abandoned woodpecker holes, 17 percent were in natural cavities, and 5 percent were in fire-produced cavities. A wide range of cavity heights and dimensions are acceptable to Bluebirds for nesting (Pinkowski 1976) as shown by the following cavity measurements of Eastern Bluebirds in two areas in Michigan:

	Mean	*Range*
Cavity height (m)	3.6	0.5 to 16.8
Entrance diameter (cm)	6.1	3.7 to 13.3
Cavity depth (cm)	19.8	7.6 to 48.3
Interior diameter (cm)	9.2	5.7 to 15.9

One way to combat the shortage of natural cavities and the competition from other birds is to provide nesting houses (fig. 2). Both Rustad (1972) and Zeleny (1973) agree the diameter of the entrance hole should be exactly 3.8 cm in order to exclude Starlings and the hole should be 15 cm from the bottom of the box. Inside floor dimensions should be between 10 by 10 cm and 13 by 13 cm. Zeleny (1973) states that the smaller floor size is more advantageous because it tends to discourage House Sparrows, which like to build bulky nests. Boxes are most effective when placed in open areas. If mounted away from bushes, House Wrens are not likely to compete. The openings should be placed toward an open field; the compass direction is not important (Rustad 1972).

Bluebirds have been known to nest year after year within a few yards of Carolina Chickadees, Tufted Titmice, Bewick's and Carolina Wrens, Great Crested Flycatchers,

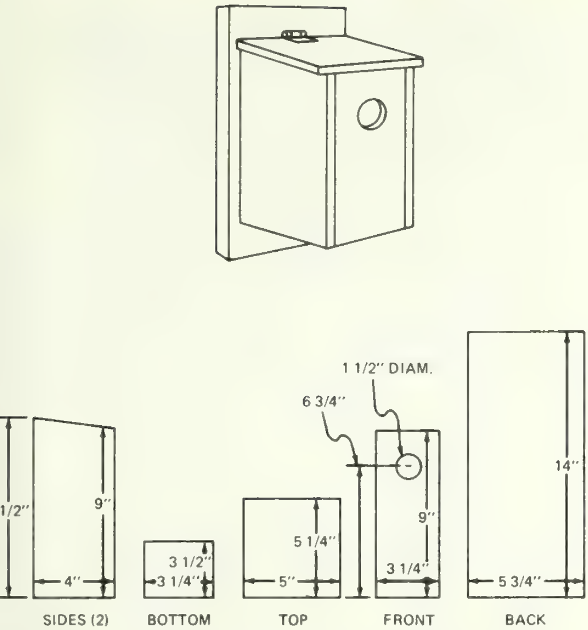

Figure 2.--*Design of a bluebird box (Missouri Conservation Commission, n.d.). The top is hinged to facilitate cleaning. Place bird box 2-5 m from ground in a sunny place along a roadside.*

ıd Flickers. This peaceful coexistence ın be achieved by the following careful lacement of nest boxes: place boxes for luebirds and Flycatchers in the open; hang ıfted Titmice boxes in trees; place ıickadee boxes, which are very small, on ›w posts under oak trees; place Wren boxes, ıich are shallow, under the eaves of low ıildings, inside sheds or barns, or on a ırch; and place Flicker boxes, which are eper than Bluebird boxes in the open 'homas 1946). Flickers adjust well to ısting in boxes. Hopefully with increased areness of the Bluebirds' present low ımbers, more boxes of suitable dimensions ıll be constructed and placed in convenient eas for them to raise successful broods. I this way, the population of these birds ıll perhaps be boosted to former levels.

On a yearly basis Bluebirds consume 6 to 70 percent animal matter and 30 to 3 percent vegetable matter. Vegetable itake increases to more than 50 percent i December and January and decreases to 0 i May. Animal matter consumed includes gasshoppers, crickets, katydids, various Cleoptera, moths and caterpillars, some Hmenoptera and Hemiptera, as well as vrious other invertebrates and an occasonal lizard or tree frog. Vegetable matter is mostly wild fruit and a few cherries, raspberries, and blackberries when available (Bent 1949). Bluebirds perch in an exposed place and fly to the ground to catch prey. In the early spring and again in summer, they catch flies on the wing and return directly to their perch to eat (Thomas 1946).

Prothonotary Warbler--*Protonotaria citrea*

The border between water and thick deciduous woods seems to be the required habitat for Prothonotary Warblers. Nests are almost always in stumps and snags that are shaded most of the day and either standing in water or within 6 m of it (Simpson 1969). Downy Woodpecker and Chickadee holes from 0.6 to 4 m from the ground are used most often (Pearson 1936). However, the warblers reportedly have a wide tolerance of the type of cavities they will use for nesting. Walkinshaw (1953) found that when nesting houses were provided, the birds preferred sites between 1 and 2 m above the water. He also reported that 82 of 84 nests located in natural sites were from 0.5 to 4.5 m above ground or water. One writer also mentioned that in Mississippi birds frequently excavate their own cavities in soft cottonwood stumps (Chapman 1907). Females build nests within the cavity in which they lay five to seven eggs. Usually the foundation is made of straw or grass, next a layer of grape vine bark is put down, and finally a thick cover of moss is added (Chapman 1907).

Prothonotary Warblers are usually absent from waterways if the woody border is less than 30 m wide. However, they do tolerate one bare bank if the opposite one has enough woody vegetation. Chapman (1907) found them to range all along the bottom lands of the Mississippi River and its tributaries as far north as southern Minnesota. During the breeding season, singing males make their territories in a linear fashion, each one covering 240 to 300 m of woody vegetation along the water's edge (Simpson 1969). Unlike many cavity nesters, Prothonotary Warblers do not winter in their breeding area but migrate as far south as Venezuela and Nicaragua in the fall (Chapman 1907).

Prothonotary Warblers are mainly insectivores. They eat ants and other insects and their larvae as well as spiders, beetles, mayflies, caterpillars, and larvae of water

insects. They usually feed low on the vegetation (trunks and branches of trees, shrubs, and fallen logs) and near water. They will also eat small mollusks which they catch from perches on rank grasses and water plants (Bent 1953).

PREDATOR-PREY RELATIONS

Insects are an abundant form of life in the forest. They exert a continuous influence through all stages of forest development. Craighead (1950) estimated an economic loss of $200 million annually to forest insects. Half of this loss is insect damage to ornamental trees. Zeedyk and Evans (1975) discuss some of the complications in assessing the value of insectivorous birds (many of which are cavity nesters) in controlling insect populations. Conclusions from searching the literature are that birds do not control epidemic insect populations, but do reduce the threat of an insect outbreak.

Observations in Arkansas and Mississippi for the past 10 years indicated woodpeckers are among the most important natural control agents of trunk-boring insects in hardwoods. The greatest service rendered by woodpeckers is the constant pressure they exert upon endemic borer populations to keep them from becoming epidemic. Predation on borers was greatest during mid and late winter (Solomon and Morris 1970).

Massey and Wygant (1973) reported woodpecker nesting increased as spruce beetle populations increased. Beetle density was associated with the woodpeckers' efficiency as predators. When beetle populations were low (1,000 to 2,500 per ha), woodpecker feeding accounted for 28 percent mortality. When beetle populations were high (400,000 per ha), woodpeckers accounted for 84 percent mortality. However, when beetle populations reached epidemic proportions (4,000,000 per ha), woodpeckers only accounted for 53 percent mortality (Massey and Wygant 1973).

Many of the trade-offs between timber management practices and habitat management practices for cavity nesters are still speculative. Literature could not be found that reported on quantified changes of timber income by leaving some dead and dying trees in the stand. It has been reported that local insect outbreaks can be checked by insectivorous birds and more than 75 percent of the broods of eastern spruce bark beetles and southern pine beetles have been destroyed in patches of bark worked over by woodpeckers (Craighead 1950). Hall (1942) reported woodpeckers were the most important single factor in the control of locust borers.

Timber-woodpecker-wood borer interrelations are further complicated by the fact that wood borers commonly attack trees with low vigor. If timber stand improvement operations leave dead and dying trees to provide cavities, these low-vigor trees may encourage an insect outbreak if other environment factors become optimum for a certain insect species.

Only limited information has been published on the influence bird populations have on insect outbreaks (Dowden *et al.* 1953, George and Mitchell 1948). When looking at the oak-hickory ecosystem, we are observing the effects of a long sequence of evolutionary processes--the result is a diverse insect population and a diverse bird population in a changing and diverse plant community. Tree species that appear to be insect resistant in a mixed hardwood stand often become vulnerable in a monoculture. A mixture of plant and animal species and age diversity adds to the stability of a community.

Similar complexities exist when attempting to quantify the forest regeneration-rodent-owl interrelations. We can state a generalization that owls consume large numbers of rodents, and rodents occasionally cause economic loss to forest regeneration attempts, but we don't have any specifics. We found no information on what limits owl populations. If owls are limited by nest sites (cavities), then an increase in abundance of cavities (or nest boxes) could increase owl populations, therefore increase predation on rodents. Much research remains to be done to answer basic predator-prey questions.

MANAGEMENT IMPLICATIONS

We found no literature that reported the results of studies designed specificall[y] to determine the impacts of silvicultural practices on the nesting habitat of cavity-nesting birds. The suggestions for management listed here are derived from synthesizing data on cavity-selection behavior. The suggestions have not been tested for

ieir effect or potential effect on pop-
.ation levels. Much research is needed
efore adequate and tested habitat models
in be designed.

Timber Stand Improvement

The most obvious and potentially det-
imental impact of timber stand improve-
ent (TSI) is the removal of culls and
iags from the forest stand. These trees
e important for providing cavities,
otential cavities, and future cavities.
i the National Forests, cutting either by
elling or shearing has essentially re-
aced herbicides in site preparation. As
result, few, if any, stems remain standing
become roost, perch, or den trees unless
ey are intentionally reserved (Zeedyk
d Evans 1975).

Conner *et al.* (1975) studied the nest-
ig habitat of Downy, Hairy, and Pileated
odpeckers, and Common Flickers. All four
ecies benefit by leaving dead snags and
ees with heart rot standing during regen-
ation cuts and subsequent thinnings.
e ideal practice on medium sites, where
land oaks grow 12 to 17 m in 50 years,
uld be to kill unwanted trees with a
lvicide and leave them standing. On
tter sites, where upland oaks grow more
an 23 m in 50 years, natural tree mor-
lity provides the best habitat and thin-
ngs may conflict with woodpecker manage-
nt. Leaving uncut filter strips along
reams and roadsides is recommended
onner *et al.* 1975).

Stand development in upland hardwoods
a dynamic process. The first 10 to 15
ars after a clearcut are referred to as
e "brush stage" when there can be as many
25,000 stems per ha. By age 20, most
the nontimber species are dead or are
legated to a subdominant position in
e stand and there are from 3,400 to
200 trees per ha present. Without thin-
ng, 90 percent of these trees will die
ring the next 60 years (Gingrich 1970).
en thinning a forest stand, subdominant,
w-vigor, silviculturally defective, and
w-quality (economic) trees are normally
moved. Therefore, silvicultural thinning
uld potentially reduce the value of the
vity nesters' habitat throughout the
rest cycle because these are the type
tree most of them prefer (Zeedyk and
ans 1975). Recent research (Shugart
et al. 1974, Perkins 1974) has considered
the impact of silvicultural practices on
nongame bird species. However, these
studies fail to discuss the availability
or potential availability of cavities.

Harvest Alternatives

Most foresters recommend managing the eastern deciduous forests with an even-age silvicultural plan. The creation of cull-free, young, fast-growing timber stands greatly reduces the cavities or the potential for cavities in a stand. Several options are available to the forester. Clearcuts should be kept small and planned so that each management unit (compartment) contains diverse stand age classes. Another alternative would be to leave 10 or 12 cull trees standing per hectare of regeneration cut. These trees could be killed by herbicide or girdling if they would conflict or compete with regeneration goals. Even when all culls and snags are felled, regeneration cuts provide several years of good feeding habitat for woodpeckers (table 9). These birds, except for Common Flickers, rely on adjacent areas for nesting cavities (table 10). Slash should not be diced, chopped, or burned unless it is absolutely necessary to accomplish regeneration goals. This extra site preparation effort is seldom

Table 9.--*Time spent by woodpeckers in four habitat types, based on a 60-hour sampling period (Conner and Crawford 1974)*

(In percent)

Species	1-year-old clearcut	5-year-old clearcut	12-year-old clearcut	Mature area
Downy	21	1	4	11
Hairy	31	5	1	6
Pileated	1	7	3	10
Flicker	2	30	1	0
Total	55	43	9	27

Table 10.--*Average vegetation characteristics of nesting sites of four species of woodpeckers (Conner and Adkisson 1976)*

Species	Nests	Basal area	Stem density	Canopy height	Age
	No.	*m^2/ha*	*stems/ha*	*m*	*years*
Downy woodpecker	17	10.1	361.8	16.3	63.6
Hairy woodpecker	10	17.2	401.3	17.8	91.2
Pileated woodpecker	15	27.1	475.3	24.2	143.5
Common Flicker	11	1.5	49.3	2.1	92.7

required in the oak-hickory forest if advanced regeneration is present (Connor and Crawford 1974).

Rotation age has a major influence on many of the cavity nesting bird species. These birds generally require mature forests for at least part of their life cycle. Short rotation cycles (pulpwood) create young, vigorous, fast-growing timber stands with very few natural cavities and dead trees. At least part of each management unit should be scheduled for a long rotation period--in excess of 100 years throughout the oak-hickory type. The Pileated and Red-bellied Woodpeckers are two examples of birds that require extensive mature forest stands. Barred Owls' preferred habitat is an oak woods that has many dead or dying trees and that is relatively free from understory brush. These conditions often exist in over-mature stands.

Guidelines

1. The literature indicated that an abundance of snags are needed in each timber stand. The exact number needed by cavity nesters will vary with the stand condition, site quality, and species of cavity nesters present. Snags are defined as completely or partially dead trees still standing and at least 3 m tall. It is generally assumed that if the snag requirements are met for the sound wood excavators (woodpeckers), they are also met for the secondary cavity users. Thomas *et al.* (1976) determined snag requirements to be approximately 45 snags per pair per species. Their model further subdivided the species into groups with similar requirements for snag size (>6 in. d.b.h., >10 in. d.b.h., >12 in. d.b.h., and >20 in. d.b.h.). Their models were developed for each timber type in the Blue Mountains of Oregon and Washington and further assumed that when the snag requirements were met for the species requiring the most snags in each d.b.h. class, then it satisfied the requirements of all other species within that d.b.h. group, and that snags present in the larger d.b.h. classes could be substituted for requirements in the smaller ones. Their model (if applied to the oak-hickory forests) indicates that 683 snags per 40 ha are required for potential maximum population of 6 species of woodpeckers nesting in the oak-hickory vegetation type. These numbers are highly speculative for the oak-hickory forests, as we do not have information on Red-headed and Red-bellied Woodpeckers (table 11) and we do not have sufficient information to test the model developed in the Northwest against oak-hickory ecosystem conditions.

Although the number of snags needed for potential maximum populations sounds high, it may not be unreasonable. An unmanaged oak-hickory stand will naturally progress from up to 25,000 stems per ha in the brush stage after clearcutting to approximately 740 stems per ha at age 80 (SI = 60). This indicates that a large number of trees die throughout the development of each mature timber stand and each dead and dying tree is normally suitable for cavities for several years before falling.

2. For generalized nongame-bird management, the land manager should strive to maintain a mixture of successional stages and forest age class categories in different size stands. This management goal is incorporated into the management guidelines of the Mark Twain National Forest in Missouri (USDA Forest Service 1973). These guidelines recommend that 10 percent of each compartment be in old growth and approximately 10 percent in permanent forage. For a 100-year rotation cycle the remaining 80 percent would be distributed as follows: 40 percent in saw logs, 30 percent in pole timber, 20 percent in sapling, and 10 percent in regenerated stands (less than 10 years old). This guideline combined with a program of leaving snags and potential snags (guideline #1) would also benefit the cavity nesting species.

3. Because some cavity-nesting species will utilize regeneration areas for feeding and 60 to 75 percent of many intensively managed forests are too young to provide adequate natural cavities (especially in the larger d.b.h. classes), Zeedyk and Evans (1975) discussed an alternative of leaving a 0.1 ha clump of trees (approximately 75) within each 2 ha of regeneration cut. This would be a 5 percent tradeoff in growing space, but, depending on placement may not be a 5 percent loss of timber production. These small clumps of older trees would provide mini-old-growth areas throughout most of the next rotation cycle. This alternative along with guideline #2 and a policy of leaving snags during TSI and harvest operations (when possible) should greatly enhance the habitat for cavity nesters.

Table 11.--*A summary of nest site characteristics of cavity nesting species*

Species	Body weight	Territory size	Max. pairs	Nest site: Min. d.b.h.	Nest site: Height min.	Nest site: Nest type[1]	Comments
	gm	*ha*	*No./40 ha*	*cm*	*m*		
Turkey vulture	1508				0	N	
Black vulture	2008				0	N	
Am. Kestrel	112	142	0.28	30	3	N	Primarily in natural cavity or Flicker hole
Saw-whet owl	89.6	40	1	30	5	N	
Screech owl	178			30	2	N	Natural cavities in apple trees, poplars
Barred owl	808			50	9	N	
Barn owl	505			50	5	N	Often nests in old buildings
Pileated woodpecker		43.0	1	30	9	H	
Red-headed woodpecker	66				7	HS	Prefer dead trunk
Red-bellied woodpecker	61.73				10	HS	Prefer dead limb
Common flicker	134.3	16.0	2	20	2	H	Will nest in clearcuts
Hairy woodpecker	43.57	3.0	13	20	3	H	Prefers live trees
Downy woodpecker	27.2	3.0	13	13	1	HS	Prefers dead trees
Red-breasted nuthatch	9.9					SN	
White-breasted nuthatch	20.7	0.8	50	30	5	SN	
Carolina wren	18.5	0.1	400			N	
Bewick's wren	11.0	0.5	80		0	N	
House wren	11.2	0.5	80	25	2	N	
Great crested flycatcher	34.4					N	
Tree swallow	19.5			25	5	N	
Purple martin	43	3.0	13			N	Will readily utilize colonial nest house
Black-capped chickadee	11.0	1.5	27	10	2	SN	
Carolina chickadee	10.1	1.5	27	10	2	SN	
Tufted titmouse	22.5				.5	N	
Eastern bluebird	30.8	1.0	40			N	Will readily utilize nest box
Prothonotary warbler	16.2	1.5	27	13	.6	N	One-half natural cavity; one-half Downy Woodpecker

[1]H = Excavator in hard snag; S = Excavator in soft snag; N = Secondary cavity user.

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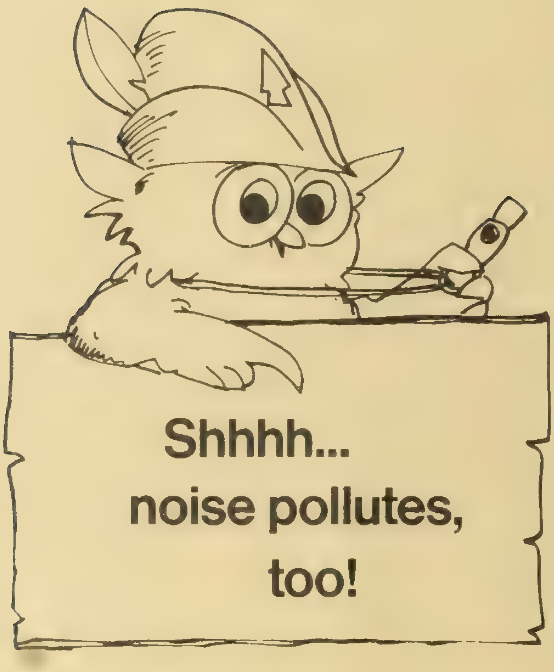
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too!

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peatland and water

in the northern lake states

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CONTENTS

PEATLAND AND WATER IN THE NORTHERN LAKE STATES

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Until recent years, hydrologic research on peatland has een limited in North America, although some intensive udies have been done in northern Europe and the oviet Union. North American hydrologists have generly ignored peatland in favor of research in areas of ater scarcity and water excess (floods). More recently ie U.S. Geological Survey has completed studies on veral large watersheds in northern Minnesota that iclude extensive peatlands.

The North Central Forest Experiment Station began udying peatland evolution in the late 50's, and in 1960 s watershed research program was expanded to include il and hydrology studies on peatland. Much research as done at the Marcell Experimental Forest in northntral Minnesota, while organic soil data have been ithered throughout northern Minnesota, northern Wisnsin, and Michigan's Upper Peninsula. These studies ere aimed at understanding the basic hydrology of eatland, the characteristics of organic soils, and the iemistry of streamflow leaving peatland.

This paper summarizes the basic principles of peatland ology, and describes in detail just what peatlands are id how they developed. The term peatland is generic id includes many classes of peat-covered terrain. We ill use terms in this paper that are accepted worldwide; owever, peatland terminology varies by country. For stance, other terms for peatland include mires in andinavia, moors in Germany, muskeg in Canada, and, forested, swamps in North America.

In their undisturbed state, peatlands normally accumute organic debris, change their vegetation, and conantly grow in depth and breadth. Growing peatland is ways associated with water. Indeed, water is required r peatland development. Peatland type depends on the nd and amount of water entering the peatland; the kind and amount of peatland in the immediate drainage basin can change the chemistry and behavior of water flowing from the basin. The northern Lake States contain a wide variety of water and peat types, and more than 6 million ha (15 million acres) of peatland occur in many sizes and locations. The large expanses of Glacial Lake Agassiz peatland in northern Minnesota contain watershed divides. Peat-filled kettle depressions in glacial tills or sandy outwash plains are common throughout the northern Lake States; they may occur near major watershed divides or at lower elevations. Streamside peatland is common on the Laurentian shield in northeastern Minnesota and other areas, and peatlands developed on old Lake Superior sand plains are common in Upper Michigan.

To understand why this diversity of occurrence exists, we need to consider the landscape before peat developed and the climate and processes during peat development. Knowing the way things were will help us understand the way things are.

LANDSCAPE DEVELOPMENT

Any discussion of peatland development in the northern Lake States (northern parts of Minnesota, Wisconsin, and Michigan) must begin with glaciers. The last glacial advance, called the Wisconsin age, lasted about 25,000 years. The southern part of the northern Lake States area was probably first revealed beneath the melt waters of the retreating Wisconsin ice sheet about 14,000 years ago in what is now central Wisconsin. Next, western Minnesota was exposed (about 11,000 years ago) and, finally, Michigan's Upper Peninsula was exposed (9,000 to 10,000 years ago).

While these glaciers were advancing to the south, they ground down the landscape and deposited a relatively flat ground moraine. After the ice melted, these flat areas provided the physical base for slow water movement, a general requirement for peat development. At various intervals, melt waters of retreating glaciers deposited flat, sandy, outwash plains that again provided a physical base for peat development.

Extensive end moraines of glacial till are also common in the northern Lake States. Today, as in the past, these hill areas provide enclosed basins where water accumulates and peat can grow.

Some areas were reworked by large lakes formed by the melt waters of retreating glaciers. Long sandy beaches are common in the Glacial Lake Agassiz region of northern Minnesota, and Glacial Lake Duluth deposited extensive sand plains well inland from the southern shore of today's Lake Superior. Lake-deposited clays and silts, lacustrine deposits, were laid down in glacial lakes away from the sorting action at their shorelines.

Finally, scattered throughout all of these land forms there are ice block depressions caused by large blocks of ice breaking off the edge of retreating glaciers leaving large depressions in the landscape when they melted. Many became lakes or ponds with limited outflow.

Thus, two landscape features conducive to peat development were left by the glaciers: flat topography and small ice-block basins. The stratigraphy of glacial drift is often complex with alternating layers of till and sorted sands. Ice-block depressions may occur in either tills or sandy outwash plains. So, why does peat develop in some areas and not in others? To answer this question we need to look at climate and water availability.

CLIMATE

Climate is the key to plant growth and decay, thus it largely controls the formation of organic soils. Although peatlands occur worldwide, they are most extensive where it is cool and precipitation exceeds evapotranspiration.

The climate of the northern Lake States is subhumid-continental. Summers are short and warm; winters are long and cold. Mean annual precipitation ranges from 508 mm (20 in) in northwestern Minnesota to 860 mm (34 in) in parts of Michigan's Upper Peninsula. About two-thirds of the precipitation occurs as rain during the warm season, April to September. Average January temperatures range from -17°C (2°F) in Minnesota to -10°C (16°F) in Michigan. Average July temperatures are about 20°C (67°F) in all three Lake States.

Clearly, this is a suitable climate for peat, but conducive climate and landforms are not enough for peat to develop.

WATER AVAILABILITY AND PEATLAND DEVELOPMENT

Peat development requires an abundant supply of water for most of the year. Conducive climate, landforms, and available water must have been present in the northern Lake States 11,000 years ago when, according to carbon-14 dates, the first aquatic peats began to form. These peats developed in kettles or ice-block depressions where the water source was either surface flow and interflow from surrounding tills or ground water supplied through sand aquifers. Water is available in tills because it collects in relatively impermeable till basins; it is available in sand basins because the water table is at or near the soil surface.

Aquatic peats in depressions were often covered by cattail, reed, and sedge peats that first developed on adjacent flat areas. The water supplied by surface flow and interflow was detained by the flat topography and, in time, by the peat itself, which tended to block drainage water, thus slowly raising the water table over long periods of time. Sedge peats began to accumulate about 8,000 years ago and are common today throughout the northern Lake States. Forested peats also began to develop about 8,000 years ago but they were limited at first to areas where calcium-enriched ground water was available. These sites occur around the edges of old glacial lake beds, on low "ridges" within the lake bed where ground water was forced to the surface by underlying bedrock ridges, and on sandy outwash areas with a high water table. In northwestern Minnesota, however, it appears that extensive forest peat development began 4,000 to 5,000 years ago after the warm Hipsithermal period. Again, the water table, usually a regional water table, rose as peats developed and blocked or slowed natural drainage.

About 3,000 years ago another type of peat (Sphag-
ım) began to accumulate as the developing peat ecame more isolated from the ground water influence. ɔhagnum peat is acid and normally not strongly fluenced by ground water. Instead Sphagnum tends to olate itself from ground water by building extensive ıt low topographic domes or extensive blankets of eat. In these areas the primary source of water is rain ıd snow. Rainfall in excess of evapotranspiration is ecessary. Only under these conditions is there enough ırface water to maintain a slightly raised water table ithin the peat mass isolated from the regional ground ater system. Today, exceptions to this occur in eat-filled ice-block depressions in sandy outwash plains here peat deposits have not built high enough to tally isolate surface water from ground water inflow. ere the high calcium bicarbonate concentrations in the coming ground water maintain peat and water pH near utral except for acid Sphagnum hummocks elevated as uch as 50 cm above the fen surface.

Peat development over the last 11,000 years has been mplex, but some generalizations will help us to derstand peatland characteristics and various concepts peatland and water management. The trend in peat velopment is from aquatic, sedge, and forest peat to hagnum peats. The sedge peat and the peat developed der the more productive forests are generally associ- ed with a ground water source containing high calcium ncentrations. Sphagnum peats, including those sup- rting the poorer forests, are associated with a rain and ow source of water that is low in calcium.

Now that we understand the general evolution of atland, we need to look at the interaction of land- rms (physiography), vegetation, and kinds (source and ality) of water in order to understand today's peat- ıds and the special names given to them.

INTERACTIONS OF WATER, VEGETATION, AND LAND

The kind of water in a peatland can determine the d of vegetation present; conversely, over long periods, kind of vegetation in a peatland can change the kind water present. Once we integrate this seeming tradiction into our concepts of peatland evolution will have a sound understanding of the way peatlands w.

Water is generally supplied from three sources: precipitation (rain and snow), ground water (regional sand and gravel aquifers), and surface flow and interflow (literal surface flow over bedrock and exposed soils or flow through surface organic horizons of mineral soils, and interflow horizontally through the A or A&B horizons of mineral soils). Calcium content is an important characteristic of water source. The three water sources typically contain different amounts of calcium: precipitation (0.3 to 2.0 ppm Ca[1]), surface flow and interflow (2.0 to 10.0 ppm Ca), and ground water ($>$ 10 ppm Ca; 20, 30, or greater ppm are not uncommon). These ranges have been verified in northern Minnesota, but not in northern Wisconsin and Michigan. Calcium is important because it commonly combines with carbonic acid (H_2Co_3) from rain to form calcium bicarbonate ($Ca(HCO_3)_2$) and this dissociates in water to yield bicarbonate ions (HCO_3^-). Bicarbonate ions are responsible for most buffering systems in natural waters and yield pH values around 6 to 8. Environments with near neutral pH values contain more plant available nutrients and a greater diversity of decomposing organisms.

We can also infer something about the relative amounts of water from these sources. Precipitation occurs fairly regularly, but its conversion to surface water is seasonal. In the northern Lake States, the snowpack and some rainfall are converted to streamflow or ground water recharge during 3 or 4 weeks in the spring. Most of the summer rainfall is converted to water vapor by evapotranspiration. Surface flow and interflow follow patterns similar to precipitation with most conversions to streamflow resulting from snowmelt or very heavy rains. Ground water sources, on the other hand, are huge compared to other water sources, and their annual distribution is more nearly uniform.

Water source is the basis for two broad categories of peatland: Ombrotrophic and Minerotrophic. These two categories cover the range of peatland types. Ombrotrophic peatlands are defined on the lower end of a total ionic concentration scale; minerotrophic peatlands cover the rest of the scale. There are corrollary names for the same categories based on vegetation; these terms are much simpler: Bog and Fen. We'll try to sort out the differences and set a foundation for understanding peatlands today.

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[1] *Calcium concentrations in precipitation may range as high as 10 ppm in northwestern Minnesota where wind-blown dust originating in the prairies can cause slightly higher pH values in peatland.*

Ombrotrophic means the peatland derives its water from ion-poor precipitation and, as a consequence, is itself ion-poor. It is inferred that the scarce ion is calcium (bicarbonate); therefore the site is usually very acidic with water pH values near 3.6. The characteristic plant of a BOG is sphagnum moss. Sphagnum also plays a major role in keeping the environment acid because of its high cation exchange capacity and the production of organic acids. The water table in a bog is often close to the surface, but usually there is little standing water (except during snowmelt or in open ponds). A raised bog is a large ombrotrophic, sphagnum bog with a characteristic dome shape. The dome is built of sphagnum and commonly occurs on top of sedge or forest (woody) peat. The central raised area is isolated from the regional water table and thus depends on precipitation for water and minerals. These peatland types may or may not be forested.

Minerotrophic means the peatland derives the major part of its water from ion-rich ground water and, as a consequence, is itself ion-rich. It is inferred that the ion in rich or large supply is calcium (bicarbonate); therefore the site is not very acid with water pH values around 6 to 7.5. Fen is a European term originally applied to grass, sedge or reed covered peatland. True fen waters are not acid and may even be slightly alkaline, but can grade into poor fens with water pH values near 4.5. Fens are generally saturated with slowly moving water or they may have temporary or semipermanent water above the soil surface. Today the term fen is also extended to minerotrophic peatlands with a forest cover; the more productive forest sites occur where mineral and water conditions are most favorable. Typically, fens have a greater diversity of plant species than bogs. Also, organic matter in the peat is more decomposed than in bogs because of a more favorable nutrient and water environment for decomposer organisms.

Water and vegetation interact to impart distinctive characteristics to each peatland area. Physiography is also an integral part of these interactions. The physiography of underlying or surrounding materials can be broadly thought of as flat areas or depressions. Flat areas are the old glacial lake beds or glacial outwash. Depressions are ice-block depressions, scoured areas in bedrock, or simply basins formed by irregular deposition of ground and end moraines. Peatland names associated with these land forms are: lake-filled and built-up peatlands.

Lake-filled peatlands have a basin type of physiography. They may either be ombrotrophic or minerotrophic, and typically have an aquatic-sedge-woody-sphagnum peat profile (bottom to top), which reflects their former lake or pond status. Ombrotrophic, lake-filled peatlands have developed in basins that are separated from the regional ground water system by very slowly permeable peat or lacustrine deposits. They have also been called perched bogs because their water table is perched above the regional water table. There may be an unsaturated zone between the bog bottom and the regional water table, or the bog basin may be nestled in the regional aquifer, but there is essentially no mixing of their waters. Water tables in minerotrophic, lake-filled peatlands are simply an exposure of the regional water table, although it may be slightly higher in the peatland due to a damming effect of the basin peat. These peatlands have also been called ground water fens because of their water source.

Built-up peatlands develop on flat areas where peat literally develops vertically because the water table rises as the peat accumulates. These peatlands commonly develop on old glacial lake plains. In addition to building up, they also spread horizontally.

Peatland terms can be confusing if they are not thought of in the context of water source, physiography, vegetation, and stage of development. Illustrations of several terms are given in figure 1. Obviously, various intergrades or transitions between peatland type occur, and our review is not exhaustive. However, the types we've discussed and the terms used should be compatible with recent wetland classification schemes for the United States. Now we can take a close look at peatland vegetation, soil, and water.

PEATLAND VEGETATION

No peatland feature has been studied as extensively as vegetation. Species occurrence has been related to topography, water movement, water chemistry, and peatland evolution. Minerotrophic sites have a larger species diversity than ombrotrophic sites (table 1). Many species that occur on ombrotrophic sites also occur on minerotrophic sites.

Fen vegetation does not include trees if there is a deep and strong waterflow such as occurs in water tracks on large peatlands. Where water tables are not totally above the surface, there is sufficient aeration for tree establishment. Northern white-cedar on organic soils indicates a forested fen. The most productive tree growth usually

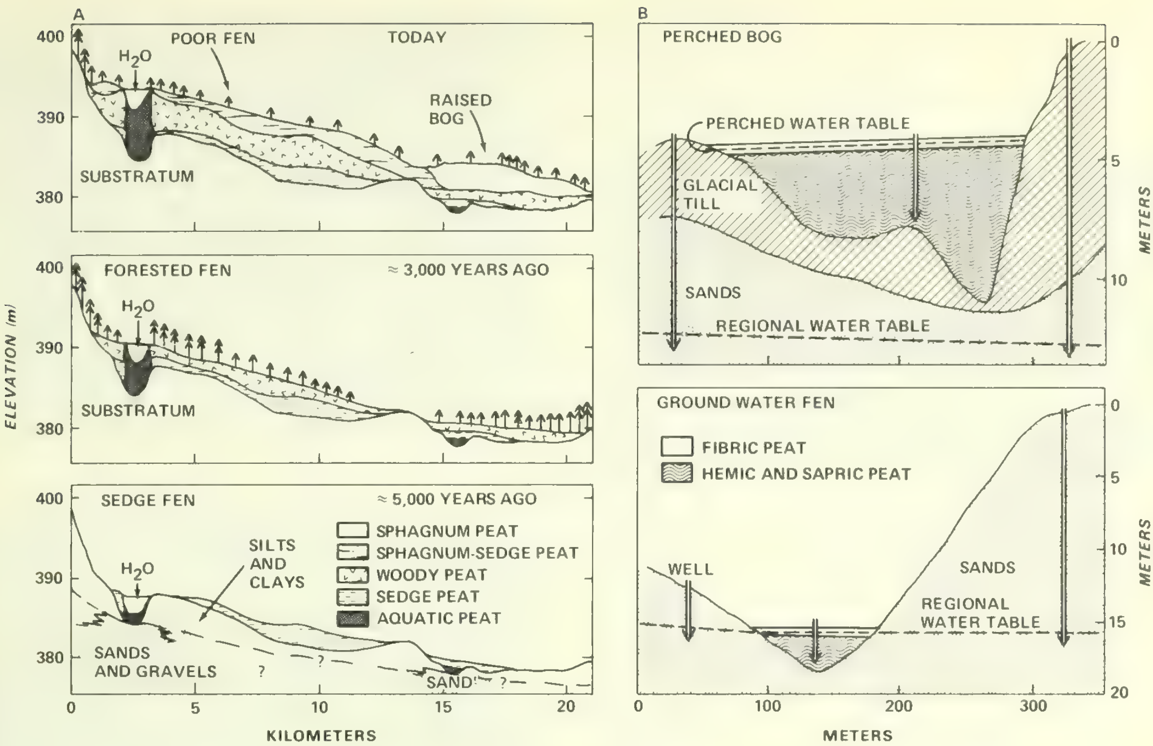

Figure 1. — *(A) Peat accumulation over 10,000 years in a built-up peatland. Peat description based on plant remains (modified from Heinselman 1963, 1970). (B) Peat accumulation in two lake-filled peatlands. Peat description based on degrees of decomposition (modified from Bay 1967).*

occurs where slopes are greatest (> 8 ft/mi) and thus ensure a balance between nutrient supply and aeration favorable for growth.

Similarly, on ombrotrophic sites, black spruce forests do best where the gradient is highest (> 8 ft/mi). The gradient results in slightly lower water tables, thus better aeration. Black spruce feather moss forests are characteristic of these sites.[2]

As seen from the air, large peatlands show various patterns: strips of vegetation radiating from the centers of sphagnum domes; patterned fen with a concave cross section that is a broad, shallow drainage channel marked by narrow ridges at right angles to the slope; teardrop shaped forested islands that appear to swim upstream in a sea of patterned fen; and water tracks, forested or nearly treeless fens, that carry the main water flow from the peatland (fig. 2). These patterns seem complex, but they are only reflecting small changes in topography, water movement, and water chemistry. A thorough treatment of peatland vegetation is cited at the end of this paper.

PEATLAND SOILS

Organic Soil Types

Peats or organic soils develop through the deposition and accumulation of organic materials in layers. The sequence and the thickness of layers vary depending on the landscape development process discussed earlier. Knowledge of peatland development is therefore essential for interpreting organic soil characteristics and in turn knowledge of organic soil characteristics is necessary for interpreting peatland hydrology.

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[2] *In the forestry profession, and in local usage in the northern Lake States, forested peatlands are often referred to as conifer swamps. Black spruce occurs on both bogs and fens, but prescribed timber management options depend on the type of peatland. Bogs are referred to as nonbrushy sites and fens are referred to as brushy sites.*

Table 1. – *Typical peatland vegetation*

Genus species	Common name	Type of site[1]	
Trees			
Fraxinus nigra	black ash	M	
Betula papyrifera	white birch	M	
Abies balsamifera	balsam fir	M	
Thuja occidentalis	northern white-cedar	M	
Larix laricina	eastern larch	A	(most frequent on M sites)
Picea mariana	black spruce	A	(most frequent on O sites)
Tall shrubs			
Alnus rugosa	speckled alder	M	
Cornus stolonifera	red-osier dogwood	M	
Salix spp.	willow	M	
Betula pumila	swamp birch	M	
Low shrubs			
Galtheria hispidula	creeping snowberry	A	
Andromeda glaucophylla	bog-rosemary	A	(most frequent on M sites)
Vaccinium oxycoccos	small cranberry	A	
Vaccinium vitis-idea	cowberry	A	
V. Angustifolium	low-bush blueberry	A	
Ledum groenlandicum	Labrador-tea	A	(most frequent on O sites)
Chamaedaphne calyculata	leather leaf	A	(most frequent on O sites)
Kalmia polifolia	bog laurel	A	(most frequent on O sites)
Herbs			
Cornus canadensis	bunch berry	M	
Rubus pubescens	dwarf raspberry	M	
Iris versicolor	Blue iris	M	
Potentilla palustris	marsh cinquefoil	M	
Menyanthes trifoliala	bogbean	A	
Smilacina trifoliata	false Solomon's Seal	A	
Sarracenia purpurea	pitcher-plant	A	
Grasses and sedges			
Calamagrostis canadensis	blue joint	M	
Carex spp.[2]	sedge	A	
Phragmites communis	reed	M	
Eriophorum spp.	cotton grass	A	
Mosses			
Sphagnum magellanicum	sphagnum moss	A	
S. fuscum	sphagnum moss	A	(more frequent on O sites)
S. spp.	sphagnum moss	A	
Polytrichum spp.	hair-cap moss	A	(more frequent on O sites)
Hylocomium	fern moss	O	(more frequent on well drained sites)
Hypmun cristata-castrensis	feather moss	O	"
Dicranum spp.	broom moss	O	"
Pleurozium scherberi	Scherbers moss	A	(more frequent on O sites)

[1]M = minerotrophic sites; O = ombrotrophic sites; A = almost all sites.

[2]Fine-leaved sedges are more common on ombrotrophic sites and broad-leaved sedges are more common on minerotrophic sites.

Peat materials and organic soils have been classified on the basis of plant origin, hence the names aquatic, sedge, woody, herbaceous, and sphagnum peats are common in the literature. More recently organic soils have been classified by degree of decomposition–the microbial breakdown of organic tissues into water, minerals, and gases. Carbohydrates and lignins are the major components of organic tissues. Carbohydrates (mainly cellulose and hemicellulose) decompose easily, but lignins, high in carbon content, resist decomposition. Indices of the degree of decomposition include ash content, humus content, color of peat or of water squeezed from peat, bulk density, and fiber content.

Fiber content is now used to classify organic soils (Histosols) in the United States. It does not depend on identifying plant remains, and it is well correlated with various physical characteristics such as trafficability, water content, water tension, water movement (hydraulic conductivity), and water yield coefficient (specific yield).

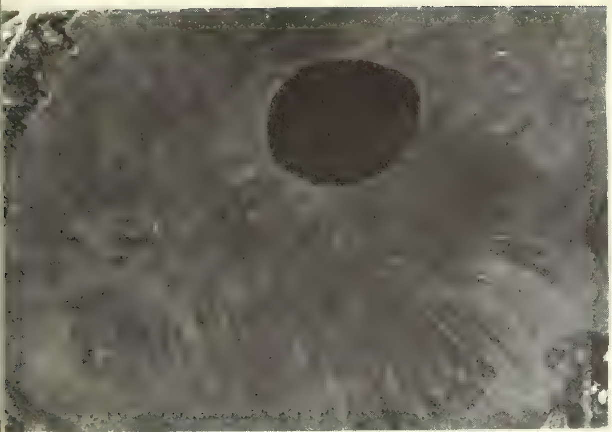


Figure 2. – *Vegetation patterns on large peatlands. (A) Radiating pattern of a sphagnum dome. (B) Patterned fen forming a water track between two large black spruce islands. (C) Teardrop shaped forest islands in a patterned fen.*

Fiber content is the portion of total peat material onsisting of fibers, fragments, or pieces of plant tissue eater than 0.15 mm in size. In moderately decomposed eat materials, fibers are decomposed and easily broken own with handling. Therefore, both resistant (rubbed) id total (unrubbed) fibers are measured.[3] Three classes ive been defined: fibric peats are the least decomposed ith a rubbed fiber content greater than 40 percent nrubbed fiber content greater than 67 percent); sapric ats are the most decomposed with less than 17 percent bbed fiber content (less than 33 percent unrubbed ber content); hemic peats are intermediate.

The organic soil profile shown (fig. 3) illustrates the ling of a lake with silt and clay followed by a marsh velopment characterized by reed and sedge remains. bove these layers is a distinct sapric horizon of well ecomposed peat that may have resulted from a lower water table, better aeration, and thus better decomposition. Sphagnum with woody inclusions characterizes the topmost horizon. The profile becomes less acid with depth, reflecting the lack of acidifying Sphagnum and pH levels of surface flow and interflow waters present today and presumably present at the time of deposition. Bulk density increases with depth because of the accumulated weight of overlying organic deposits. Fiber content usually decreases with depth, reflecting a greater degree of decomposition. However, fiber content does not always follow this pattern because woody horizons have high fiber content due to the slow decomposition of lignins, and, at lower depths, mineral inclusions strongly bias fiber content and other determinations.

[3] *Fiber content is measured by collecting the fibers on 100-mesh sieve using a gentle stream of water to wash way particles smaller than 0.15 mm. Rubbed fiber ontent is measured by first rubbing the peat material etween the thumb and forefinger.*

Organic Soil Physical Properties

The physical, and consequently, hydrologic characteristics of peat materials are closely related to the degree of decomposition (table 2). Water freely drains from saturated fibric peats and a great deal more can easily be squeezed from them than from partially decomposed

Horizon label & depth	Horizon description	Fiber content	Bulk density	Soil pH in H_2O
cm		percent	g/cm^3	
A 0 to 15	Fibric peat--Undecomposed sphagnum moss and leaves of heath shrubs.	90 to 98	0.015 to 0.028	4.2
B 15 to 30	Fibric peat--Relatively undecomposed sphagnum moss and roots of heath shrubs.	70 to 80	0.050 to 0.075	4.2
C 30 to 45	Hemic peat--Moderately to well decomposed sphagnum moss with wood inclusions.	40 to 45	0.08 to 0.19	4.4
D 45 to 60	Sapric peat--Well decomposed aggregated peat with no recognizeable plant remains.	15 to 30	0.21 to 0.26	4.1
E 60 to 100	Hemic peat--Moderately decomposed herbaceous peat from reeds and sedges.	40 to 55	0.12 to 0.17	4.8
100 to 200	Hemic peat--Moderately decomposed sedge peat.	--	--	5.4
200 to 225	Sapric peat--Well decomposed aquatic peat mixed with considerable sand.	--	-- (very dense)	5.3
225+	Lacustrine silt and clay	--	--	5.4

Figure 3. – *An organic soil profile from a lake-filled perched bog.*

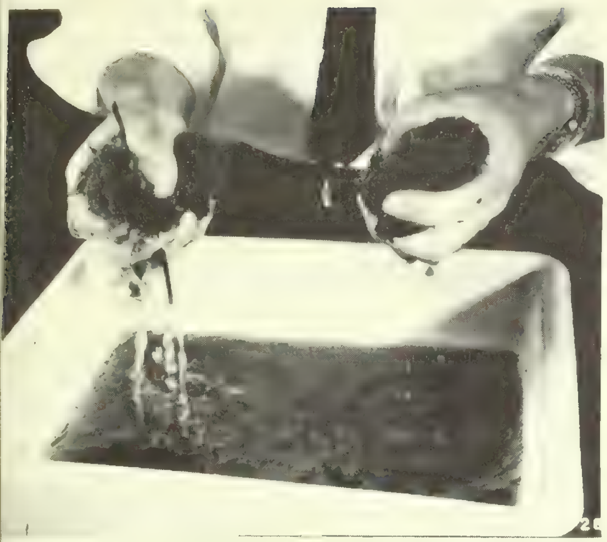
Table 2. – *Range of important physical characteristics of fibric, hemic, and sapric peats from northern Lake States peatlands*

Degree of Decomposition	Total Porosity	Specific Yield	Hydraulic Conductivity	Bulk Density
	- Percent volume -		*10^{-5} cm/sec*	*g/cm^3*
Fibric	> 90	> 45	> 150	< .09
Hemic	84 - 90	10 - 45	1.2 - 150	.09 - .20
Sapric	< 84	< 10	< 1.2	> .20

peats (fig. 4). A hole excavated in fibric peat materials will usually fill with water to the water table elevation in the peatland in a matter of minutes.

Partially or well decomposed (hemic or sapric) peat in deeper horizons reacts differently. Little water can be drained from a sample of these peats and little can be squeezed from it even though it is saturated. If a hole is excavated in this material and water is excluded from surface fibric layers, it may be weeks before the water in the hole reaches the peatland water table elevation.

All peat types, regardless of plant source or degree of decomposition, contain more than 80 percent water by volume when saturated, indicating a high total porosity. The nature of this porosity, however, is different. The undecomposed (fibric) peats contain large, easily drained pores that permit rapid water movement. These peats release 50 to 80 percent of their water to drainage and have hydraulic conductivities as high as 4.0×10^{-2} cm/sec (120 feet per day). Well decomposed (sapric) peats yield only 10 to 15 percent of their water to drainage. Most of the water is retained in many small pores that are not easily drained. Hydraulic conductivities of these peats are as low as 7.0×10^{-6} cm/sec (0.02 foot per day).



'igure 4. — *A large amount of water drains from the undecomposed sphagnum moss peat on the left; very little water runs from the partially decomposed peat on the right. Both were saturated.*

The degree of decomposition, as measured by fiber 'ontent and bulk density, is well correlated with water ension (tenacity with which water is held in soil pores), nd thus with water content and hydraulic conductivity. [he relations between these measurements (fig. 5, table) can help predict the success of peatland drainage. The ase of drainage can be seen by looking at the difference etween the saturated and 0.1 bar lines because this ifference defines the water that easily drains from a soil nder the force of gravity. The decrease in water content s large for fibric peats and much less for sapric peats.

Similarly, the rate of water movement (usually hori- ontal) through saturated organic soils is well correlated o degree of decomposition as measured by fiber content nd bulk density. The rate of saturated water movement hrough fibric peats is a thousand times faster than the ate of saturated water movement through sapric peats fig. 6).

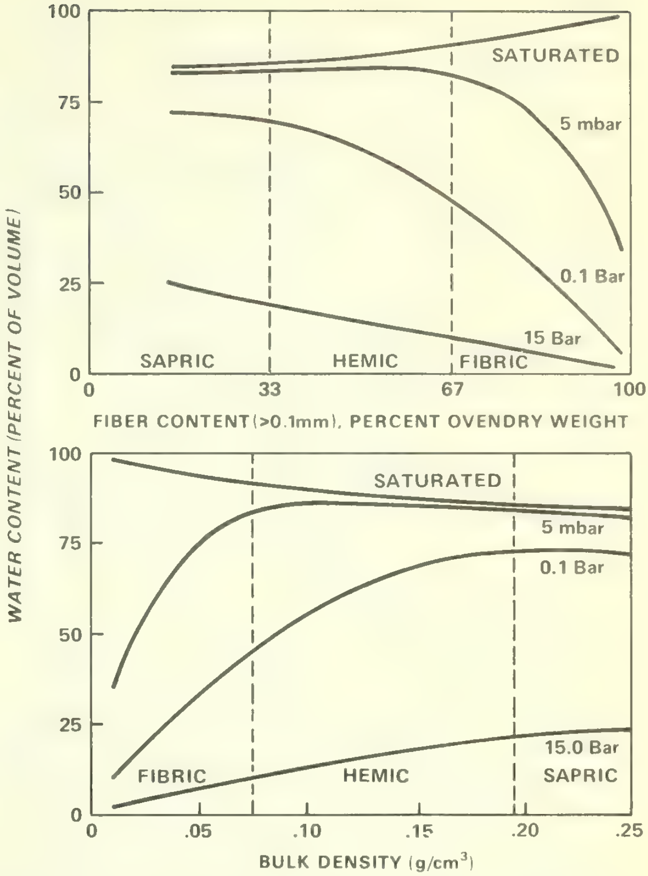


Figure 5. — *The relation of water content at saturation, 5 mbar, 0.1 bar, and 15 bar suctions to unrubbed fiber content (> 0.1 mm) and bulk density (Boelter 1969).*

Table 3. — *Curvilinear regression equations and coefficients of multiple determination (R^2) for the relation of water content (Y) at saturation, 5 mbar, 0.1 bar, and 15 bar suctions to fiber content (> 0.1 mm) and bulk density*[1]

Independent variable (X)	Regression equation	R^2
	Saturation	
Fiber content	$Y = 84.23 - .0279X + .00185X^2$	.68
Bulk density	$Y - 99.00 - 123.45X + 252.92X^2$	.68
	5.0 mbar	
Fiber content	$Y = 52.45 + 1.5619X - .01728X^2$	.69
Bulk density	$Y = 39.67 + 638.29X - 2{,}010.89X^2$	.70
	0.1 Bar	
Fiber content	$Y = 67.91 + .4136X - .01064X^2$	.80
Bulk density	$Y = 2.06 + 719.35X - 1{,}809.68X^2$	.88
	15.0 Bar	
Fiber content	$Y = 29.34 - .3420X + .00072X^2$	.73
Bulk density	$Y = 1.57 + 115.28X - 107.77X^2$	.82

[1]Boelter (1969).

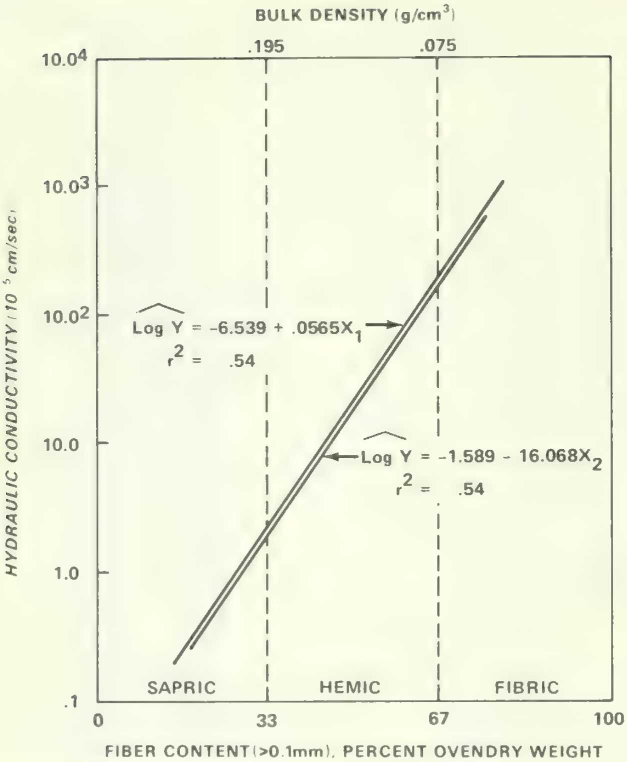


Figure 6. – *The relation of hydraulic conductivity (Y) to unrubbed fiber content (X_1) (> 0.1 mm) and bulk density (X_2) (Boelter 1969).*

PEATLAND AND WATER

Peatlands and water have held a rather mysterious place in the folklore of many peoples. The popular conception of peatlands sees them as huge natural sponges that soak up spring snowmelt and gradually release it to streamflow throughout the dry summer months. This is certainly an over-simplification at best and can lead to misunderstanding of a complex natural system.

Certainly anyone who has walked on a peatland will agree that the surface is "spongy", but the effect on streamflow does not automatically follow. A sponge must be squeezed to get much water out of it and there is no way of squeezing peatland. True, some water can be drained from peatland the same way that water will seep out of a completely saturated sponge for a short time. Also, water will flow through a saturated sponge in large amounts if there is a continuous supply, such as a faucet dripping on top. Similarily water will flow horizontally through a saturated peatland. However, a saturated sponge without a continuous supply of water will quickly dry out by evaporation and little water will flow from it; such is also the case with ombrotrophic peatlands during summer. The processes that affect sponges also affect natural peatland, but their net effect on natural streamflow does not follow the popular conception.

Hydro-Geologic Settings

Perhaps the major reason for conflicting hydrologic values attributed to peatland is failure to appreciate the influence of water source and physiography. Lake-filled peatlands may or may not be part of the regional water system (fig. 1). Those that are not are either perched above the regional water table or sealed off from any significant influence of ground water. These perched bogs receive water from precipitation, surface flow, and interflow. Thus their streamflow depends on snowmelt and rain frequency and the balance of precipitation and evapotranspiration. Lake-filled basins that are part of the regional water system receive the same water inputs as perched bogs, but they also receive much larger amounts of ground water, thus their streamflow mostly depends on the transmissibility and storage of water in regional aquifers that discharge to the fen surface. Ground water will enter the fen surface at the "uphill" edges because the basin peat acts like a dam in the regional water system; or it will enter the fen through "vertical windows" (amorphous channels) from the sand aquifer to the peat surface (fig. 7). These windows are conspicuous in mild winters when they do not freeze over like the rest of the fen. They are, in effect, artesian wells.

Built-up peatlands on large glacial lake beds or outwash plains have similar water sources, but with significant variations. The raised bogs, with their characteristic convex domes, receive only precipitation. Ground water will enter built-up peatlands from uphill edges or it can enter through artesian wells (windows) that can range up to lake size. Time works against the efficiency of artesian water supplies because the amorphous channels gradually become plugged with organic material. The plugging also modifies the water by removing calcium through cation exchange on the peat. Thus ground water becomes less minerotrophic as it moves through or across organic soils. Some artesian windows of earlier geologic times may have been completely covered by deep peat deposits acting as an aquiclude (aquifer seal). Shallow peats over sand plains

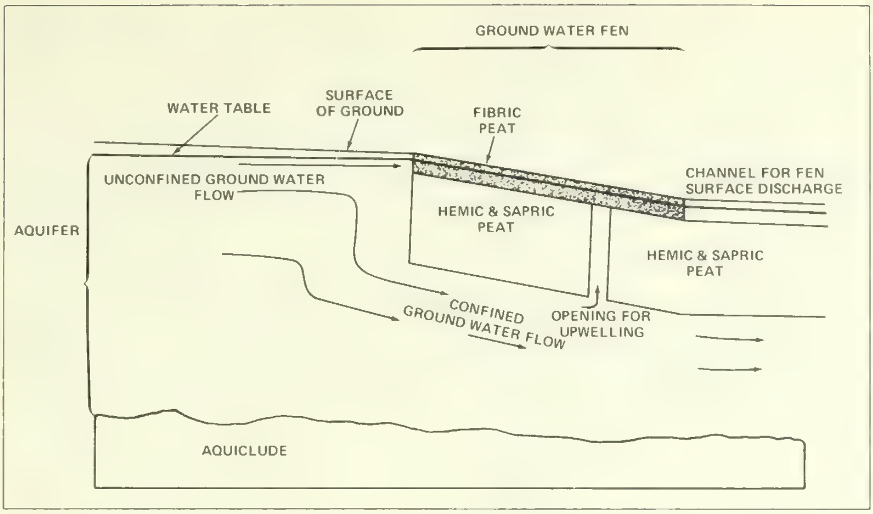


Figure 7. – *Schematic cross section of ground water flow in the region of a ground water fen on the Marcell Experimental Forest (modified from Sander 1976).*

n be fed by capillary water from a water table close to e sand surface. In this situation, peat development pends greatly on fluctuations of the regional water ble that may lower the capillary fringe below the reach vegetation and evapotranspiration demands.

Peatland Water Tables

Peatland water levels depend on water source. This lation can be illustrated by comparing the regional ater table and the water tables of both a perched bog d a ground water fen (both lake-filled basins) within 8 km (1/2 mi) of each other on the Marcell Experiental Forest (fig. 8).

Water levels of the regional aquifer measured in wells ljacent to each lake-filled peatland basin show similar ends over several years (fig. 8a). A low point is reached ch winter before snowmelt. When snow begins to melt d frost disappears, the water table steadily recharges sually during April and May). By mid-June the water ble recharge is interrupted by high evapotranspiration mands. This, coupled with discharge to surface areas, counts for the steady decline of the water table until e next snowmelt-spring rain recharge cycle. The high ak in 1966 resulted from heavy fall rains in 1965 and e melting of an exceptionally deep snowpack in March d April of 1966. During years of both normal and ove-normal precipitation annual water table fluctuans in the ground water fen are less than in the perched g because ground water input tends to smooth out the ter table fluctuations caused by precipitation and apotranspiration (fig. 8b and c).

The response of peatland water tables to precipitation depends on the type of peat material in the zone of active water table fluctuation. This is best illustrated by comparing water table response to rain in a perched bog where the water table fluctuation is great enough to encompass both fibric and hemic peat materials in the same profile. There is a distinct difference in response to rain between the upper (fibric) and lower (hemic) peat materials (fig. 9). Both water table hydrographs were produced by rainstorms of nearly equal amount and intensity. The difference is due to the initial position of the water table in different peat types. Storm A occurred after a midsummer drying period when the water table was 25 cm (0.8 feet) below the surface and in moderately decomposed (hemic) peat. Storm B occurred in the spring when the water table was at the average bog surface in live, undecomposed sphagnum mosses.

Peatland water tables may also be affected by vegetation. Closed-in canopies of black spruce will intercept 15 to 20 cm (6 to 8 in) of rain and snow per year, thus forested peatland receives less precipitation on the peat surface than does nonforested peatland. Harvesting a peatland forest may or may not raise the water table, depending on water source. In ground water-fed peatlands the differences in precipitation reaching the surface will probably not be reflected in water table fluctuations because the supply of water from the regional aquifer greatly exceeds precipitation. The effect of ground water supply simply overrides the effect of forest harvesting. In perched peatlands, however, the effect of forest harvesting on water tables depends on

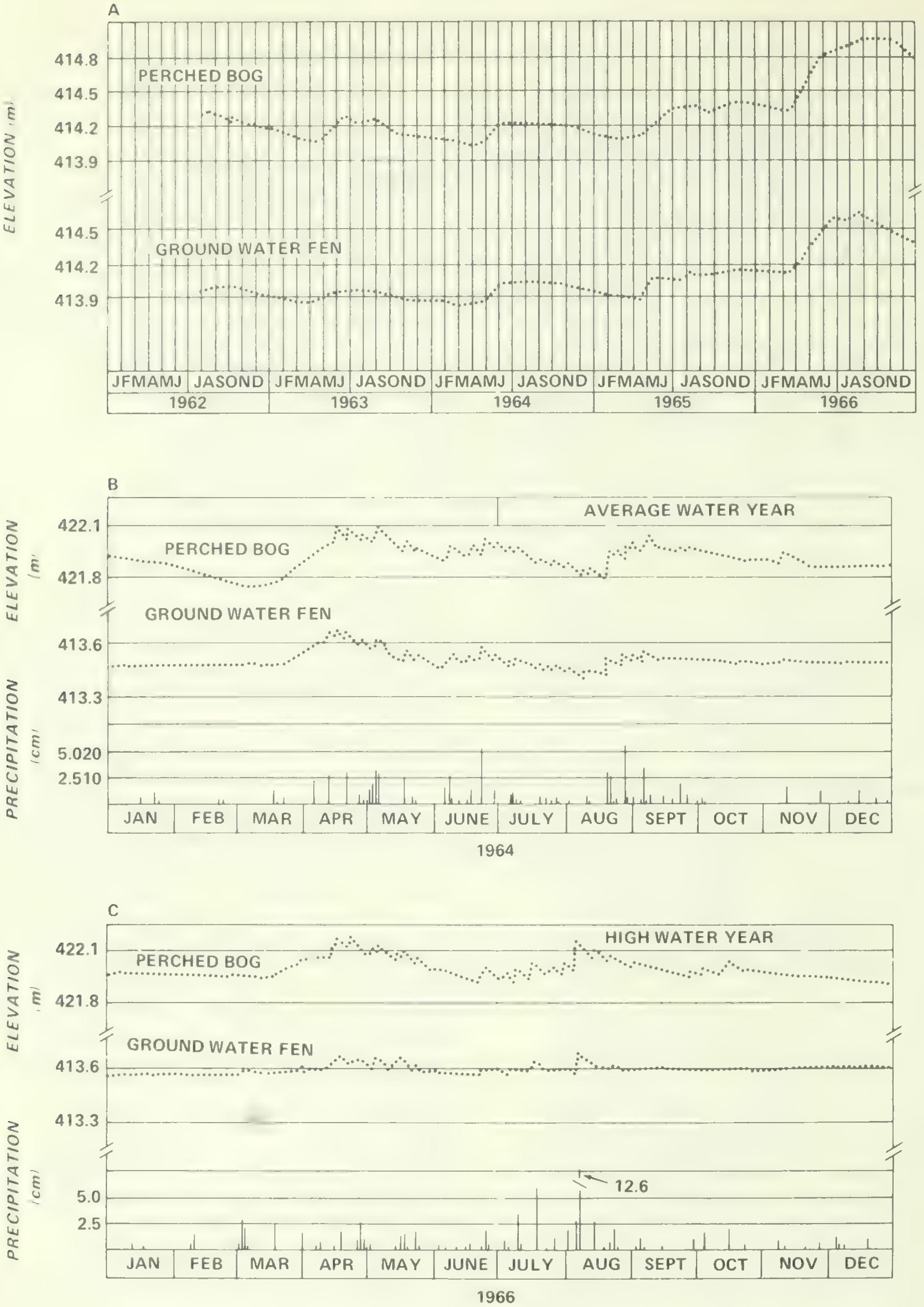


Figure 8. *(A) Water levels in deep wells on the upland watersheds surrounding a perched bog and a ground water fen. (B) 1964 water tables in a perched bog and ground water fen. (C) 1966 water table levels in a perched bog and ground water fen (Bay 1970).*

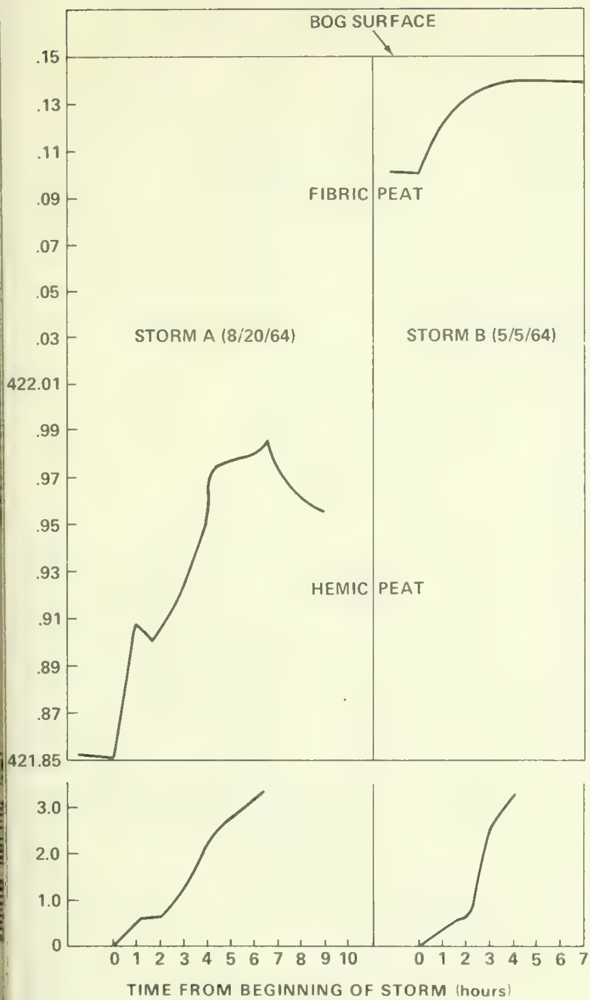


Figure 9. — *Water table response to storms of equal size depends on initial water table elevation and the degree of decomposition at that point. The water table response to Storm A is four times that of Storm B.*

the frequency of rainfall. During prolonged dry periods water tables will be lower after harvesting because of an increase in surface wind and a large increase in the biomass of transpiring sedges which can pull water from lower depths than Sphagnum. With increasing rainfall frequency, water tables in harvested areas will be higher because there is less interception loss.

Evapotranspiration

Annual evapotranspiration from forested peatland is, in general, similar to potential evapotranspiration calculated by the Thornthwaite method. Long-term annual potential evapotranspiration in the northern Lake States is 533 mm (21 in) with a range of 432 to 584 mm (17 to 23 in). Monthly values range from 2.5 mm (0.1 in) in March and November to more than 100 mm (4 in) in June, July, and August. One study in north-central Minnesota measured actual evapotranspiration from a forested bog by the water balance method. Over a 6-year period, the evapotranspiration from May 1 to November 1 ranged from 465.1 to 526.3 mm (18.31 to 20.72 in).

Water table level affects the rate of evapotranspiration so that day-to-day rates do not correspond to calculated potential evapotranspiration. Evapotranspiration from an open sphagnum bog with a grass, sedge, and *Ericaceae* cover is greatest when water level is 10 cm (about 4 in) below the bottom of hollows because the evaporative surface of sphagnum moss is greatest at this point and grass and sedge roots are well aerated. Raising the water table above this point will decrease evapotranspiration because grass and sedge roots are flooded as is some of the evaporative moss surface. Dropping water levels to 33 cm (about 13 in) below the bottom of the hollows will drastically reduce evapotranspiration because the capillary fringe does not reach to the surface mosses and herbaceous roots. At this point, surface mosses will dry out, and herbaceous sedges and grasses will be dominated by *Ericaceae* shrubs with xeromophic features such as thick leaves with waxy layers and fuzzy undersides.

Streamflow from Peatlands

Streamflow is the net effect of all processes that influence the hydrologic cycle of a watershed. Streamflow is most easily measured on small watersheds containing lake-filled peatland (fig. 10). Although these small watersheds contain both peatland and their associated uplands, they provide data on the overall effectiveness of peat deposits as water storage areas and regulators of streamflow. Perched bog basins are easiest to measure because nearly all the streamflow from the peatland is measured at the weir (fig. 11). Ground water fens are difficult to measure because stream gages do not measure all the discharge and the contributing area of ground water is uncertain.

Most of the annual flow from perched bogs occurs before June 15, while the distribution of flow from ground water fens is much more uniform. This striking difference in seasonal streamflow distribution from perched and ground water basins is shown by the monthly percentages for two basins on the Marcell Experimental Forest (fig. 12).

Figure 10. – *Aerial view of a small watershed with a perched bog in the center. The approximate watershed boundary is shown as a dashed line.*

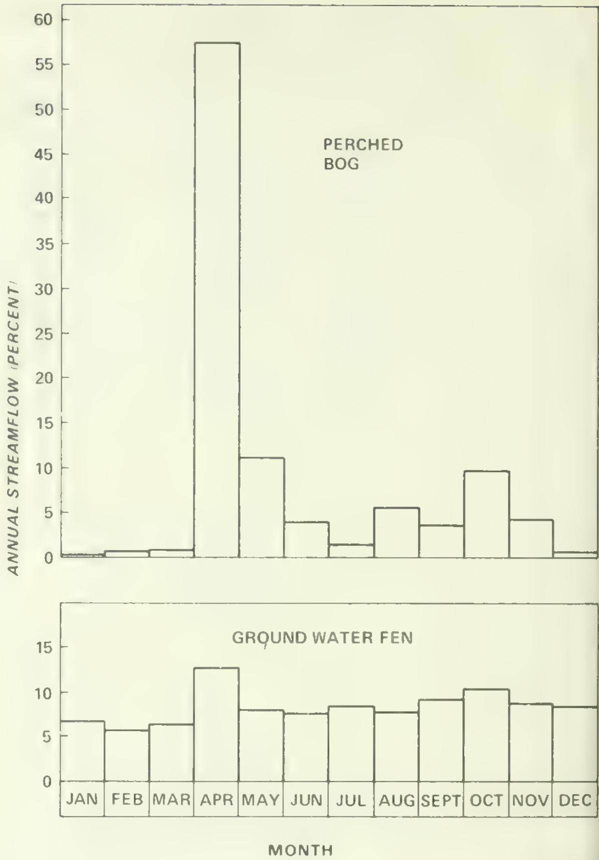


Figure 12. – *Monthly distribution of annual streamflow from a perched bog and a ground water fen, 1969.*

Figure 11. – *Stream gauge for measuring run-off from a perched bog and surrounding watershed.*

The large portion of annual runoff from perched bogs in April results from melting snow, early spring rains, high antecedent soil moisture conditions, and low evapotranspiration. By the end of snowmelt, the water level is generally near the surface in perched peat deposits, and these peat deposits behave much like lakes or reservoirs filled with water: additional water quickly contributes to streamflow. Streamflow is low during late spring, summer, and early fall, even though much of the annual precipitation occurs then (fig. 13). This rainfall is quickly returned to the atmosphere by evapotranspiration at the expense of streamflow and deep seepage. Evapotranspiration increases with increased solar radiation and the return of annual leaves. On the Marcell Experimental Forest in north-central Minnesota, average rainfall for the period May 1 to November 1 is 546 mm (21.5 in) and evapotranspiration estimates average 505 mm (19.9 in). Assuming no changes in storage, average runoff for the period is 41 mm (1.6 in), less than 8 percent of the rainfall. Only large summer rains will significantly increase streamflow.

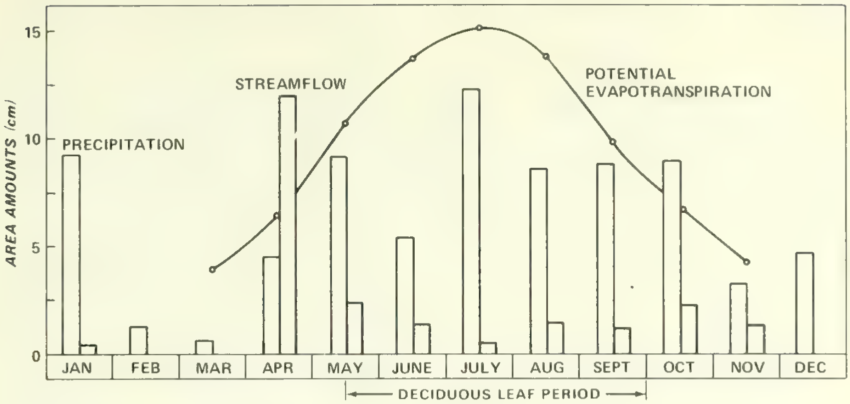


Figure 13. – *Monthly precipitation, streamflow, and potential evapotranspiration for a perched bog watershed, 1969 (modified from Verry and Boelter 1975).*

The uniform distribution of annual streamflow from the ground water fen can be explained by the behavior of the regional water table (fig. 14). Over winter there is a gradual decline in the water table. With the beginning of snowmelt and disappearance of frost, there is a quick, sustained high rate of recharge. The high recharge occurred April 8-24 and extended about 5 days beyond the disappearance of snow. From late April until mid-June there is another stable, though lesser rate of recharge. This reflects drainage from unsaturated soil and parent material and may include short periods of saturated flow following spring rains. By mid-June, however, the continuity of water flow to deep seepage is broken as summer rains usually replenish soil moisture depleted by high evapotranspiration. This coupled with discharge to surface areas, such as fens, accounts for the steady decline of the water table until the next snowmelt-spring rain recharge cycle.

Some have speculated that peatlands, because of their high water storage capacity and flat slope, regulate the distribution of streamflow. This does not appear to be so in small lake-filled bogs in bog-upland watersheds. Streamflow from perched bogs is not well regulated; flow duration curves have steep slopes because streamflow and evapotranspiration depletes basins that have little perennial storage (fig. 15).

Streamflow from ground water-influenced peatland is much more uniformly distributed because the fen is a surface discharge point for the regional ground water system, which provides a more constant supply of water. The flow duration curve is nearly flat, and shows a nearly constant rate of flow 70 percent of the time because of the large amount of perennial storage. The characteristics of streamflow are again due to the hydro-geologic characteristics. Only a minor effect is due

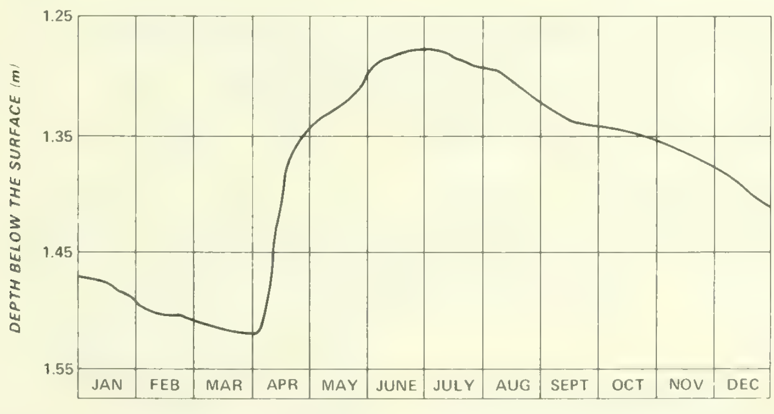


Figure 14. – *Hydrograph of the regional ground water table on the Marcell Experimental Forest, 1969.*

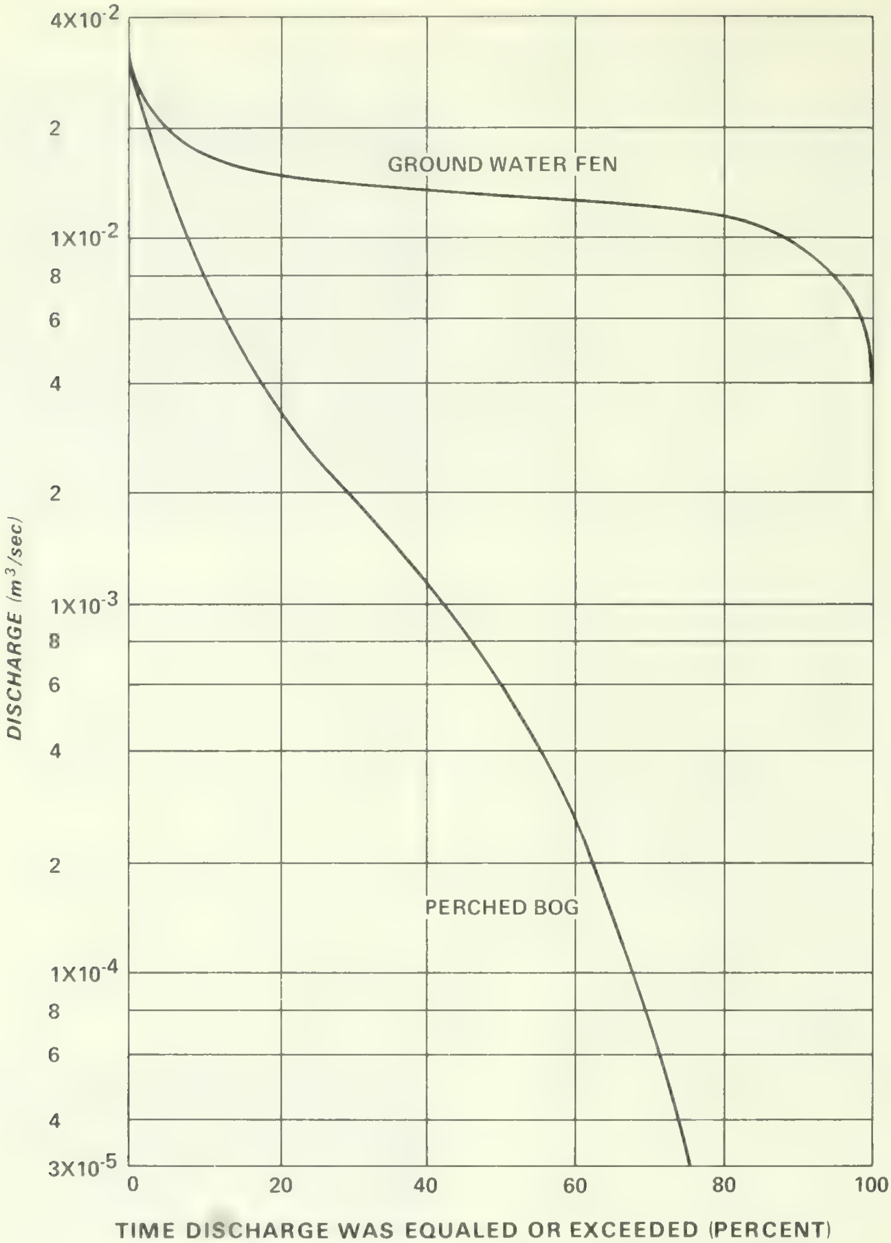


Figure 15. – *Streamflow-duration curves for a ground water fen and perched bog watershed. Both watersheds are about 53 ha in size.*

to the fen. Instead of regulating streamflow, the ground water fen may do the opposite by releasing excess water more quickly than mineral aquifers during periods of high precipitation and losing more water by evapotranspiration during dry periods.

Stormflows are generated by heavy rains, but the most common contributor to maximum annual streamflow rate is snowmelt. Maximum streamflows (floods, if you will) are not a function of the kind of basin, perched or ground water. Rather, they are affected by watershed size, the amount of water in the snowpack, the rate of snowmelt, infiltration characteristics of the basin soil, and the percentage of peatland or lake in a watershed. The two watersheds represented in figure 15 are about the same size, have the same snow and rainfall and about the same percentage of peatland, and thus have the same maximum streamflow rate even though one watershed contains a perched bog and one contains a ground water fen.

Stormflows resulting from spring, summer, and fall rains are modified by peatland. Typical storm hydrographs from perched bogs have long, drawn out recession curves (fig. 16). The recession leg of the dormant season hydrograph approaches a straight line on semi-logarithmic paper rather quickly and remains well above the prestorm discharge level. This characteristic indicates a temporary storage and slow release of storm flows due primarily to the nearly level bog topography and the large detention storage of surface peats. The recession leg of the growing season hydrograph is broken by daily evapotranspiration losses that reduce streamflow. However, the storage and slow release of stormflow are still evident from the small decay rate (flattening of the hydrograph) during periods of low evapotranspiration.

Peak stormflows are related to climatic and physiographic variables including the short-term storage capacity of the watershed. In organic soils, storage capacity depends greatly on the level of the water table in the peat profile. Therefore, storm peaks are directly related to water table level (fig. 17). Greatest runoff occurs when the water table is high because there is little available storage capacity and water moves directly to the bog outlets. Surface peats also have high hydraulic conductivity and drain quickly while deeper peats are more decomposed, retain more water, and drain slowly.

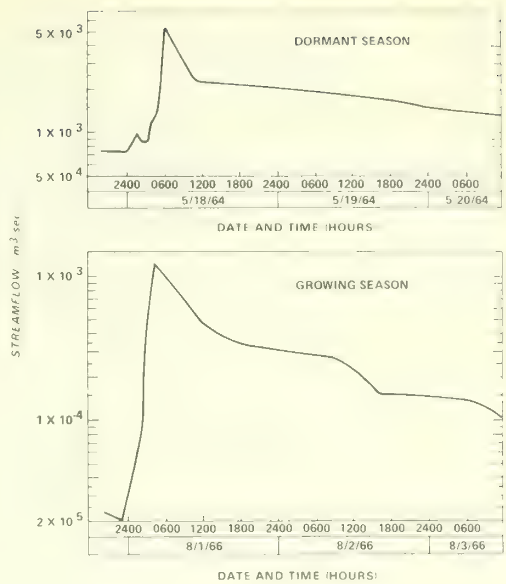


Figure 16. – *Hydrographs for a dormant season storm (2.5 cm) and a growing season storm (2.2 cm) on a perched bog watershed (modified from Bay 1969). Note the nearly straight recession leg for the dormant season storm while the growing season recession leg is broken by daily evapotranspiration losses.*

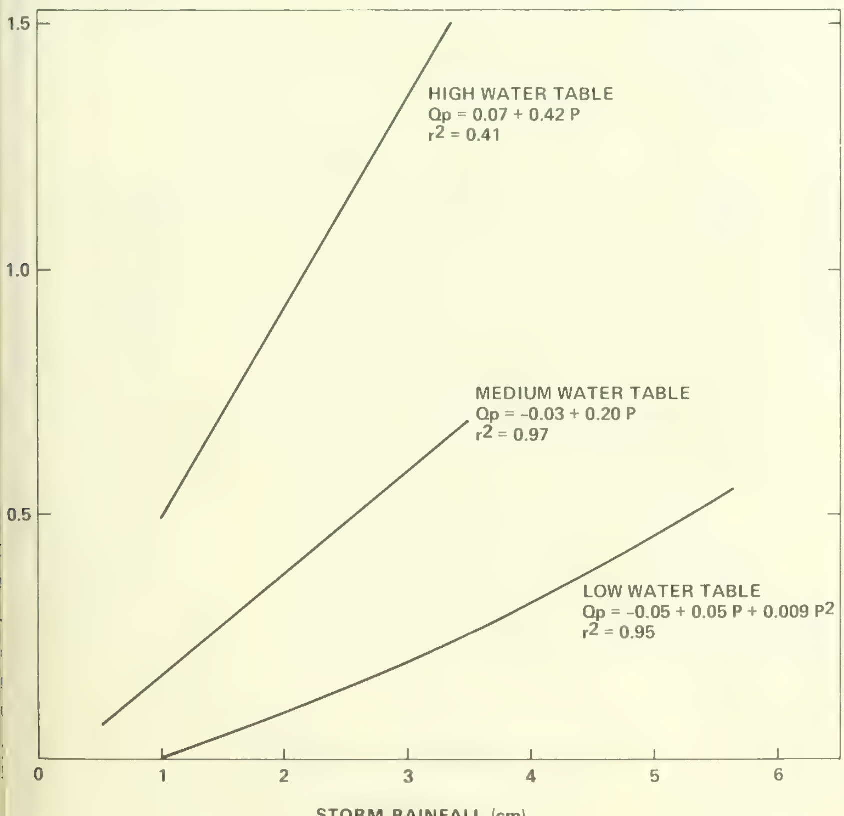


Figure 17. – *Relation of peak flow (Q_p) to storm rainfall (P) and water table position in a perched bog. High water table conditions existed when water tables were fluctuating above the average moss surface and within the hummock and hollow micro-topography. Low water table values were computed when water tables were greater than 15 cm below the average hollow elevation (modified from Bay 1969). Watershed size is 9.7 ha.*

We have considered peatland hydrology largely from data gathered on small watersheds around 40 ha in size, but similar conclusions have been reached for large watersheds in northern Minnesota where peatland constitutes 40 percent or more of the area. In general, water is released from peatland very slowly and is not a significant source of low streamflow. In peatland areas, water is discharged mostly by evapotranspiration. Streamflow is maintained by discharge from ground water reservoirs and lakes. But both lakes and flat peatland areas reduce flood peaks.

Half of the popular concept concerning peatland and water is true. Peatland does reduce the peak rates of streamflow from snowmelt and heavy summer rains because it is flat and there is some short-term detention storage in the surface horizons. However, peatland does not sustain streamflow during dry summer months by slowly releasing stored water. To the contrary, it uses water at maximum rates of evapotranspiration and at the expense of streamflow.

Peatland Water Chemistry

Peatland water chemistry depends on the kind and amount of water source and the distance water has traveled through the peatland. Ombrotrophic raised bogs and perched bogs reflect precipitation chemistry and have a narrow pH range because Sphagnum moss controls acidity through cation exchange reactions. In general, ombrotrophic bog waters have a pH of 3 to 4, a specific conductance less than 80 μ mhos, and a calcium concentration less than 4 or 5 mg/1. The predominant anion is sulfate and the predominant cation is hydrogen (table 4).

Fens, fed by a ground water source, generally have water pH values of 4 to 8, a specific conductance more than 100 μ mhos, and calcium concentrations more than 15 mg/1. The predominant anion is bicarbonate and the predominant cation is calcium. Poor fens have values grading downward into the ombrotrophic values. Minerotrophic fens in general have a much wider range

Table 4. — *Average concentration of water quality indicators in the streamflow of perched bog and ground water fen watersheds*[1]

Water characteristics	Perched bog watersheds				Ground water fen watersheds			
	$\bar{x}$	±	SD	N[2]	$\bar{x}$	±	SD	N[2]
Color units	136	±	145	170	100	±	64	22
pH units	3.6	±	0.3	93	6.5	±	0.28	15
Specific conductance (µmho at 25°C)	51	±	13	104	125	±	[illegible]	16
MG/LITER								
Total acidity 1± (as $CaCO_3$)	48.2	±	24	132	-	±	--	--
Total alkalinity (as $CaCO_3$)	--	±	--	--	54.2	±	28.0	18
Total-N	1.34	±	0.64	167	0.58	±	0.29	21
Organic-N	[illegible]	±	0.40	165	0.33	±	0.22	21
Ammonia-N	0.45	±	0.39	165	0.15	±	0.14	21
Nitrate-N	0.20	±	0.25	168	0.10	±	0.07	21
Nitrite-N	0.003	±	0.003	166	0.003	±	0.003	21
Total-P	0.06	±	0.06	136	0.03	±	0.01	17
Cl	0.7	±	0.8	172	0.4	±	0.4	22
SO_4	[illegible]	±	2.2	73	6.0	±	4.2	7
Fe^{++}	1.35	±	0.8	166	0.98	±	0.48	21
Ca	2.4	±	1.0	170	16.6	±	9.0	22
Na	0.6	±	0.3	164	2.0	±	1.0	22
Mg	0.97	±	0.36	136	2.88	±	0.93	15
Mn	0.06	±	0.05	136	0.08	±	0.06	14
K	1.3	±	0.6	128	1.1	±	0.4	22
Al	0.79	±	0.43	135	0.16	±	0.06	14
Pb[3]	<0.05	±	--	116	<0.05	±	--	12
Zn	0.08	±	0.11	123	0.11	±	0.17	12
Si	2.7	±	2.1	49	4.9	±	4.0	3

[1]Verry (1976).
[2]Number of samples.
[3]Usually below detection limit of 0.05 mg/liter.

chemical values because there is great variation in the nds and amounts of ground water. Some perched bogs lake-filled basins might have a thin boundary of poor n resulting from mineral soil surface flow and inter-ow, but the volume of flow is not large enough to ercome the exchange capacity of Sphagnum peats ore than a few meters from the bog edge.

In large, built-up peatlands the minerals in ground ater may be depleted by cation exchange as they flow rther and farther away from their source. A progres-on of rich to poor fen results. Poor fens can also result om ground water low in dissolved minerals (especially lcium). The amount and type of dissolved minerals in ound water depends on the mineralogy of the aquifer d confining units and the time that water has traveled contact with various materials.

Annual yields of nutrients have been calculated for pland-peatland watersheds containing perched bogs in orth-central Minnesota (table 5). Because the sphagnum ogs control the chemistry of these small watershed reams, the values should also apply to other ombro-ophic bogs such as raised bogs in built-up peatlands.

ble 5. — *Annual yield (kg/ha · yr) of nutrients and other chemicals for perched bog watersheds, WS-2 and WS-4*[1]

Chemical constituent	WS-2[2]	WS-4[2]
Total-N	1.91	1.97
Organic-N	0.99	1.02
Ammonia-N	0.64	0.66
Nitrate-N	0.28	0.29
Nitrite-N	0.01	0.01
Total-P	0.08	0.08
Cl	0.87	0.87
SO_4	7.75	9.17
Fe	1.81	1.66
Ca	3.46	3.55
Na	1.06	1.25
Mg	1.46	1.52
Mn	0.08	0.08
K	1.26	1.41
Al	1.12	1.04
Zn	0.08	0.09
Si	1.71	1.21
Total acidity (as $CaCO_3$)	72.01	74.19

[1]Verry (1976).
[2]WS-2 and WS-4 refer to numbered watersheds on the Marcell Experimental Forest in north-central Minnesota.

The annual yields of nutrients are similar to those from other undisturbed forested watersheds in humid areas of the northern United States and southern Canada.

It has not been possible to calculate annual nutrient yields from a ground water fen because the contributing area of ground water is difficult to determine. However, we can compare the concentrations for the ombrotrophic, perched bog and minerotrophic, ground water fen (table 4) by weighting them by amount of annual streamflow. Weighted concentrations for the two watershed types are similar for organically derived ions (total-P, total-N, and total-Fe) and for chloride, which is mainly atmospheric in origin and moves freely in the environment (table 6). Weighted concentrations of minerals derived from solution of aquifer and overburden materials are greatest in the ground water fen watershed.

In general, nearly equal amounts of organically derived nutrients are leached from both watershed types in an equal volume of water leaving the watershed as streamflow. The total yield (kilograms/year) of all chemical constituents is primarily a function of the annual volume of streamflow.

Table 6. — *Average annual flow weighted*[1] *concentrations for perched bog and ground water fen watersheds (g/m^3) (annual streamflow averages for WS-2, WS-4, and WS-3 are 16,278, 67,429, and 574,954 m^3, respectively*[2]

Chemical constituent	Perched bog watersheds		Ground water fen
	WS-2[3]	WS-4[3]	WS-3[3]
Total-P	0.05	0.04	0.03
Total-N	1.1	1.0	0.6
Total-Fe	1.1	0.8	1.0
Cl	0.5	0.4	0.4
K	0.8	0.7	1.1
Al	0.67	0.53	0.16
SO_4	3.6	3.5	6.0
Na	0.6	0.6	2.0
Mg	0.9	0.8	2.9
Ca	2.1	1.8	16.6
Mn	0.05	0.04	0.09
Zn	0.05	0.04	0.11
Si	1.0	0.6	4.9

[1]Perched bog watershed concentrations have been weighted by flow rate for some nutrients which show an inverse relation between flow rate and concentration.
[2]Verry (1976).
[3]WS-2, WS-3, and WS-4 refer to numbered watersheds on the Marcell Experimental Forest in north-central Minnesota.

SUMMARY

Peatland is different from other land forms in many ways. Formed as a result of excessively wet conditions, peatland remains saturated or nearly saturated in its natural undrained condition. Although these conditions have led to speculation that these wetlands play a unique hydrologic role, this role may not be as different as first thought.

Although saturated and containing 80 percent or more water by volume, organic soils do not always permit rapid water movement or easily give up their water to drainage because the more decomposed materials hold their water tenaciously.

Peatland can be broadly classed into two groups: ombrotrophic (ion-poor) peatland (bog) receives precipitation as its primary water source; minerotrophic (ion-rich) peatland (fen) receives large ground water supplies as well as precipitation.

Contrary to popular belief, neither bogs nor fens maintain an even distribution of annual streamflow. Seasonal distribution within the year is governed primarily by the hydrogeologic setting, water source, and evapotranspiration relations. The organic soils have only a minor effect. The flat topography and physical detention of flow in the surface layer do regulate individual stormflows by reducing peaks and delaying the release of stormflow volumes.

The water chemistry of streams draining peatland depends primarily on water source. Nutrients in rain, snow, and dust, modified by organic soils and Sphagnum moss, play a major role in the composition of on-site water in ombrotrophic peatland, but they do not greatly affect the ionic composition of streams draining large areas of land. The water composition of streams draining minerotrophic peatland is primarily determined by the solution of ground water aquifer and overburden parent materials. The downstream influence of peatland in large watersheds is only seen in color values and perhaps some organically derived anions. Concentrations of these materials decrease with distance from the peatland.

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Nature is beautiful...leave only your footprints.

manager's handbook for

JACK PINE IN THE NORTH CENTRAL STATES

GENERAL TECHNICAL REPORT NC-32

NORTH CENTRAL FOREST EXPERIMENT STATION   FOREST SERVICE   U.S. DEPARTMENT OF AGRICULTURE

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FOREWORD

This is one of a series of manager's handbooks for important forest types in the north central States. The purpose of this series is to present the resource manager with the latest and best information available in handling these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. However, ways to modify management practices to maintain or enhance other values are included where sound information is available.

The author has, in certain instances, drawn freely on unpublished information provided by scientists and managers outside his specialty. He is also grateful to the several technical reviewers in the region who made many helpful comments.

The handbooks have a similar format, highlighted by a "Key to Recommendations". Here the manager can find in logical sequence the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbook. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objective. The manager should also apply new research findings as they become available so that the culture of these important forest types can be continually improved.

CONTENTS

JACK PINE

IN THE NORTH CENTRAL STATES

John W. Benzie, *Principal Silviculturist*
Grand Rapids, Minnesota

SILVICAL HIGHLIGHTS

Wildfires following early pine logging, and extensive anting programs in the 1930's, increased the extent of ck pine[1] in Minnesota, Wisconsin, and Michigan. owever, its present area of 2.5 million acres[2] is ecreasing as jack pine stands are converted to other ecies.

Jack pine grows in extensive pure stands but is also equently mixed with red and white pine, aspens, paper rch, and scrub oaks; less often it is mixed with black ruce, white spruce, and balsam fir. Jack pine is tolerant of shade. It is often a pioneer species on burns bare sandy soil and is usually succeeded by more lerant species on all but the dry sandy sites where it ay form an edaphic climax.

Although jack pine is a short-lived tree, a few dividuals may live for more than 200 years, and stands metimes survive up to 100 years. Commercial rotation es are generally between 40 and 70 years when mature es are usually 8 to 12 inches d.b.h. and 50 to 80 feet l.

Jack pine is susceptible to severe losses from several diseases and insects, as well as from browsing or girdling by animals, and from breakage by wind, ice, hail, and snow storms. Fires also easily kill jack pine but they play an important role in establishing many seedling stands by killing the shrub and tree competition, preparing seedbeds, and melting the resin on the scales of the serotinous cones to release seeds.

Cones are generally serotinous over much of the jack pine range; many of these closed cones persist on the tree for years resulting in large accumulations of seed in unopened cones. Some trees, however, particularly in the southern part of the jack pine range, bear non-serotinous cones which open as soon as they mature and disperse their seeds promptly. Good seed crops are produced at 3- to 4-year intervals from about age 20, but best seed production is on trees 40 to 50 years old.

Considerable variations in vigor, wood characteristics, stem and crown form, cone characteristics, and resistance to insects and disease provide opportunities for genetic improvement.

MANAGEMENT OBJECTIVES

Jack pine is a short-lived, intolerant, pioneer species at occurs primarily as a temporary type on the better es, but on the deep, dry outwash sands, where other mmercial tree species do poorly, it is a more perman-t type. Management objectives considered in this handbook are (1) to maintain the jack pine type where it is the best suited species and (2) to replace it with a more suitable species on other sites at the end of the jack pine rotation. Intermediate thinnings are recommended for jack pine stands on the better sites (site index 60 or more) managed for the production of poles and small saw logs. Most jack pine stands, however, will be managed for pulpwood without intermediate thinnings except for densely overstocked seedling stands that need to be weeded to reduce the risk of stagnation, shorten the rotation, and increase the pulpwood yield.

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[1] *For scientific names of plants and animals, see ppendix, p. 15.*

[2] *For metric equivalents, see Appendix, p. 15.*

Jack pine seedlings require full sunlight to become established. The recommended silvicultural system may be clearcutting, seed tree, or shelterwood, depending on various conditions such as seed tree quality, cone habit, slash disposal methods, and seedbeds. Planting may be needed to establish jack pine on some sites but on many areas scattering branches with serotinous cones or sowing repellent-treated seed on mineral soil seedbeds will be successful. Natural regeneration by the seed tree or shelterwood system depends on the availability of good quality seed trees. The seed tree system is recommended only for stands with serotinous cones where prescribed burning can be used for site preparation and the heat of the fire will open the cones on the seed trees. If the trees have nonserotinous cones, the shelterwood system may be used.

Major problems in managing jack pine stands involve stand establishment and protection. Weather conditions are often more critical on dry sandy soils where droughts and high temperatures can severely hinder stand establishment. Protection problems are also influenced by weather factors that increase environmental stresses on the trees. Wind, snow, ice, and hail storms can be especially damaging to jack pine stands. Other problems include insects, diseases, and fire.

The acreage of jack pine increased after the original pine logging because wildfires encouraged natural seeding and there were extensive planting programs in the 1930's. These jack pine stands show large differences in growth rates and pest resistance. Many areas could be more productive if improved jack pine seeds or trees were used for establishing new stands on these sites or if the jack pine stands were replaced with a more productive forest type at the end of the rotation. Better guidelines are needed to select improved jack pine for establishing stands on the dry, sandy sites where jack pine has an advantage over other species and to compare jack pine productivity with other suitable species on all sandy sites.

Jack pine forests can be managed for timber and still provide wildlife habitat for several species of mammals and birds including deer, hare, and Kirtland's Warbler. Practices to ensure and protect other resources such as recreation and water along with timber are also discussed in the handbook.

KEY TO RECOMMENDATIONS

The following key is based primarily on the technical aspects of forest management – silviculture, protection, and regulation. The administrative aspects – economic, legal, and social – have only limited indirect influence in the key so the user is cautioned to evaluate these aspects carefully when applying the technical recommendations.

The key recommends management practices for some of the common site and stand conditions encountered in the jack pine type or on potential jack pine sites. Use of the key in conjunction with a stand examination will lead to one or more general recommendations. Each recommendation refers to the appropriate section under "Management Considerations" where optional silvicultural tools and methods are discussed.

To use the key, start with the first pair of numbered statements. Choose the statement that best describes the situation and find a number only, a recommendation and a number, or a recommendation only. If a number is given, find the pair of statements with that number and continue the process until a recommendation only is reached. All recommendations encountered in going through the key should be considered in your prescription.

1. **Jack pine stand with minimum or higher stocking** . . . .
   See "Type" and "Stand Density", p. 4, and fig. 5, Appendix
1. **Jack pine stand with less than minimum stocking, or area is nonstocked** . . . .
   2. **Average tree d.b.h. is less than 5 inches** . . . .
      See "Size", p. 4
   2. **Average tree d.b.h. is 5 inches or more** . . . .
3. **2,000 or more trees per acre** . . . . WEED OR CLEAN .
   See "Weeding and Cleaning", p. 6
3. **Less than 2,000 trees per acre** . . . .
   4. **Stand is mature** . . . .
      See "Rotation Ages", p. 7
   4. **Stand is not mature** . . . .

Site index 60 or better 6
See fig. 4, "Appendix", p. 11

Site index less than 60 9

6. Manage for large products (poles, etc.) 7
See "Quality", p. 5

6. Manage for small products (pulpwood, etc.) 9

120 square feet of basal area per acre or more . . . . THIN . . 9
See "Thinning", p. 6

Less than 120 square feet of basal area per acre 9

8. Severe overstory competition . . . . RELEASE . . 9
See "Release", p. 6

8. Overstory competition is not severe 9

High risk of injury or loss . . . . CONTROL IF FEASIBLE
See "Risk", p. 4

Low risk of injury or loss . . . . WAIT

10. Condition is needed for other resources . . . . MAINTAIN
See "Other Resources", p. 9

10. Condition is not needed for other resources 11

Jack pine desired *and* site is suitable 12
See "Site Evaluation", p. 7 and "Conversion", p. 9

Jack pine not desired; *or* jack pine desired but site not suitable . . . . CONVERT

12. Desirable jack pine seed source on area 13
See "Seed Tree Requirements", p. 8

12. No desirable jack pine seed source on area . . . . USE CLEARCUT . . 17

Trees have serotinous cones 14
See "Seeding", p. 9

Trees have nonserotinous cones 16

14. 10 trees per acre are adequate to seed area 15
See "Silvicultural Systems", p. 8

14. 10 trees per acre are not adequate to seed area . . . . USE CLEARCUT . . 17

Prescribed burning is planned . . . . USE SEED TREE
See "Site Preparation", p. 7

Prescribed burning is not planned . . . . USE CLEARCUT . . 17

16. Two commercial harvests possible and desired . . . . USE SHELTERWOOD . . 17
See "Silvicultural Systems", p. 8

16. Two commercial harvests not possible *or* not desired . . . . USE CLEARCUT . . 17

Sufficient mineral soil seedbeds free of slash and competition 18
See "Site Preparation", p. 7

Insufficient or inadequate seedbeds . . . . PREPARE SITE . . 18

18. If shelterwood system is used . . . . USE NATURAL SEEDING
See "Silvicultural Systems", p. 8

18. If clearcutting system is used 19

Improved planting stock available . . . . PLANT
See "Planting", p. 9

Improved planting stock not available 20

20. Good supply of serotinous cones on area . . . . SCATTER CONES
See "Seeding", p. 9

20. Poor supply or no serotinous cones on area . . . . DIRECT SEED

TIMBER MANAGEMENT CONSIDERATIONS

Stand Conditions

Jack pine stands and potential jack pine sites need to be carefully examined on the ground to best determine their condition, but use of aerial photos, maps, and other sources of information should not be overlooked. The stand – or site – condition, which is the basis for recommendations, includes type, age, size, density, risk, quality, productivity, and operability.

Type

Jack pine grows in extensive pure stands as well as various mixtures in which it is the predominant species. Common associated species in mixed stands are red and white pine, quaking and bigtooth aspen, paper birch, northern red oak, and northern pin oak. Other associates include black spruce, white spruce, balsam fir, and bur oak. In addition to the species composition of the main stand, important understory tree or shrub species should be noted so they can be evaluated for site preparation needs and for other single or multiple uses. Dry, sandy areas that are nonstocked or poorly stocked may be suitable sites to establish jack pine seedlings.

Age

The total age of dominant and codominant trees will aid in estimating site productivity and comparing the present stand with its potential condition. Total age in jack pine can be estimated by adding 6 years to age at breast height (4.5 feet above ground) or 2 years to age of plantations. Rotation ages for jack pine are discussed on page 7.

Size

Jack pine stands are classified as seedling stands (up to 2 inches average d.b.h.), sapling (2 to 5 inches), pole (5 to 9 inches), and sawtimber (9 inches and over). Estimated tree diameters and basal areas at age 20 are strongly influenced by stand density and site (tables 1 and 2, p. 12, Appendix). In stands with more uniform stand density, tree size will also be more uniform.

Stand Density

Two important aspects of stand density in jack pine stands are the stocking level and uniformity. As the stocking level decreases toward the minimum stocking, uniformity or distribution of the trees in the sta increases in importance. The minimum stocking in bas area and number of trees for uniform stands of vario average stand diameters was calculated from the max mum amount of growing space trees of each diamet could use (fig. 5, p. 11, Appendix). Minimum stocki for stands averaging 4 inches in diameter is about 6(trees and 50 square feet of basal area per acre. In stan averaging 12 inches in diameter minimum stocking about 100 trees and 80 square feet of basal area per ac The recommended upper limit of stocking for manag stands is based on 85 percent of a normal yield table f pole stands (5 to 9 inches average diameter) and 1(percent for sawtimber stands (fig. 5, p. 11, Appendi The recommended upper limit of stocking for manag stands averaging 5 inches in diameter is about 800 tre and 110 square feet of basal area per acre. For stan averaging 9 inches in diameter it is about 300 trees a 140 square feet of basal area per acre.

In seedling stands less than 5 years old stocking can estimated by percent of milacre plots with at least o seedling (a "stocked" milacre). A minimum of percent stocked milacres would provide good seedli distribution and indicate at least 600 trees per ac which is the recommended minimum stocking for stan averaging 4 inches d.b.h. In older seedling stands (ove years old) 1/100-acre sample plots are recommended estimate number of trees per acre and average tree si Although understocked stands are generally more o problem than overstocked stands, dense sapling stands to 5 inches average d.b.h.) with more than 2,000 tr per acre develop weak spindly trees that may tend stagnate.

Risk of Loss from Damaging Agents

High risk jack pine trees are those damaged diseases, insects, animals, fire, or weather. Risk depe on the degree of injury and the chances for the tree recover. Trees in young, vigorous, fully stocked sta have the best chances.

Weather damage includes flooding, drought, lightn strikes, and breakage by ice, hail, snow, and w storms. Storms may also leave thin-crowned weake trees susceptible to further injury from other envir mental stresses.

Fire damages jack pine of all sizes. Surface fires kill seedlings and saplings and hot fires someti

ompletely kill pole stands. Trees that survive fires are often scarred and weakened making them poor risks. Prescribed burning is not recommended in immature ack pine stands. Firebreaks should be used to help educe the spread of wildfires.

Jack pine seedlings may be severely browsed by deer which sometimes kill trees up to 10 years old. Browsing etards height growth and often deforms young trees. Dense seedling and sapling stands provide good cover for nowshoe hares that may girdle many trees during high opulations. Porcupines sometimes seriously damage lder trees by stripping the soft bark near the tops of arge trees.

Many insects attack jack pine. One of the most serious ests is the jack pine budworm. The budworm defoliates rees of all sizes but the older, less vigorous trees growing nder stress, such as on poor sites and during droughts, uffer greater losses. Losses are related to the intensity f defoliation and the vigor of the trees and include tree nortality, reduced volume and lower quality caused by op kill, reduced growth, and reduced seed production. Trees weakened by budworm defoliation are more usceptible to other insect pests such as the ips bark eetle. Bark beetle outbreaks on healthy trees occur when the insect population builds up in fresh slash or on weakened trees and can successfully attack neighboring rees, especially during drought conditions. Vigorous tands have less risk of injury from insect attacks. Best ontrol measures are to harvest budworm-infested stands t 40 years of age or as soon as merchantable to iscourage further buildup. Risk of bark beetle attacks n healthy trees can be reduced by removing fresh slash rom around residual trees, such as by full-tree skidding.

Other insects that are found on jack pine include the pine root collar weevil, several pine sawflies, pitch odule maker, pine chafer beetle, white pine weevil, pine tussock moth, pine tortoise scale, eastern pine hoot moth, pine tip moth, Zimmerman pine moth, pine webworm, and a root tip weevil. Although these insects nay cause severe losses on occasion, the risk can be ninimized by maintaining vigorous stands.

Diseases of jack pine include several stem rusts such as astern gall rust, stalactiform rust, sweet fern rust, omandra rust, and western gall rust. Other important liseases include Armillarea root rot, Scleroderris canker, nd *Fomes pini.* Trees weakened by drought, or by other njuries, have the greatest risk of succumbing to attacks.

Quality

Jack pine tree quality is related to size, form, straightness, branching habit, and damage caused by injuries. Low density stands tend to have poorer quality trees because of more taper, crookedness, and larger branches; but overdense stands with more than 2,000 trees per acre can produce weak spindly trees that are also poor quality. Most jack pine stands will probably be managed for small roundwood products such as pulpwood but some stands – especially on the better sites – can be managed for poles and small sawtimber if the trees are reasonably straight, have little taper, small branches, and little or no injury that will hinder their growth and development. The wide range of genetic variation in jack pine makes it possible to improve future stands by selecting the best quality trees for seeding new stands.

Productivity

Site index is the height attainable by the average dominant and codominant trees in relatively pure, even-aged, and well stocked stands at the age of 50 years (see page 11 and fig. 4, Appendix). The productivity of a *stand* can be estimated from its site index with the aid of the growth and yield tables in the Appendix (tables 3-7). Volumes in cubic feet and cords are shown for site indices 40, 50, 60, and 70 at several different ages and for stand densities of 30, 60, 90, 120, and 150 square feet of basal area per acre (tables 4 and 6, Appendix). Current annual growth is also shown for these same stand conditions (tables 5 and 7, Appendix) so that growth of any stand can be projected for the next growth period. If projections are made for more than 10 years, it would be best to interpolate a new current annual growth from the table or use the equations given in the table to compute the periodic annual growth for the period desired.

Operability

Markets, access, and volume of products that are removed determine operability. The value of the product is also important so higher value products will usually make the stand operable with lower volumes. It is suggested that jack pine stands have a minimum volume of 100 cords at maturity or a minimum area of 10 acres but about 40 acres are recommended for establishing new stands.

Controlling Composition and Growth

Release

Jack pine is so intolerant that it cannot survive long with overhead shade. On very dry sites, however, especially during droughts, some shade from trees, shrubs, or slash may be beneficial by lowering surface temperatures and reducing evapotranspiration. As soon as seedlings are established they should be given full sunlight on all sites. Jack pine seedlings grow rapidly in height after the first couple of years and can usually keep ahead of the competition except on the better sites. Where competition is more than just a few trees or shrubs the most practical control method is with herbicide foliage sprays. The use of chemical herbicides requires strict adherance to label instructions. Two of the most useful herbicides are 2,4-D and 2,4,5-T.[3] Jack pine may be injured by these herbicides if spraying is done too early. Spraying should be done in the first 2 weeks of August for good control of hardwoods and because the risk of injuring jack pine is low. Most of the common competing species can be controlled with 2,4-D but blackberries, raspberries, roses, juneberries, prickly ash, oaks, and maples are resistant to it. All of these species except the maples can be controlled with 2,4,5-T. Maples are difficult to control with foliar sprays but felling the tree and spraying the stump with chemicals containing 2,4,5-T is effective.

Weeding and Cleaning

Overstocking of jack pine seedlings and saplings occurs less frequently than understocking but dense stands with 2,000 or more trees per acre should be weeded or cleaned for improved growth and development. Weeding is done during the seedling stage of stand development and cleaning during the sapling stage to provide more growing space for the potential crop trees. Seedling and sapling stands do not usually have merchantable material so weeding and cleaning are often referred to as "precommercial thinning". In very dense stands (i.e., 10,000 trees per acre) mechanical methods that clear strips about 8 feet wide and leave strips of trees about 2 feet wide are more efficient than operations that leave 800 to 1,000 uniformly spaced crop trees.

Thinning

Jack pine stands on the better sites (site index 60 and over) can be thinned to about 80 square feet of basal area per acre to increase the production of poles an small saw logs. Thinnings should not remove over one third of the basal area to minimize post-logging mor tality. Dense stands may require a couple of thinnings t safely reduce the basal area to 80 square feet per acre Removing every third, fourth, or fifth row is recom mended only when economics or high stand densitie prevent marking individual trees. Thinnings shoul generally be from below – removing the smaller, slowe growing trees to favor the larger crop trees, but high risk poor quality, or damaged trees of any size should b removed to improve the stand. In mixed stands, th more valuable or desirable species should be favored. O these better sites jack pine is a temporary type that wi most likely be replaced by a more suitable species at th end of the rotation.

On the less productive sites or in stands managed fo small roundwood products such as pulpwood, thinning are not recommended (fig. 1).

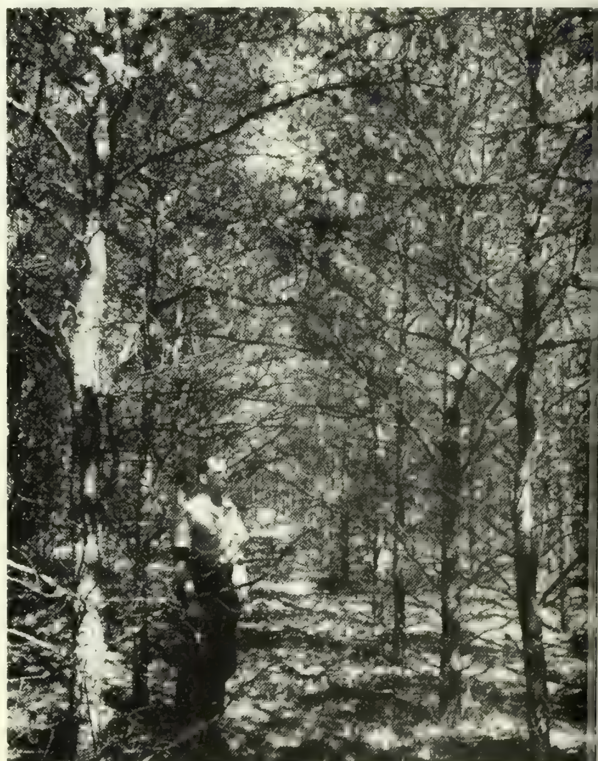

Figure 1. – *Jack pine planted at 7 x 7 foot spaci produces a uniform stand at age 20 and will n require thinning for a pulpwood rotation of 40 to . years.*

[3] *See Pesticide Precautionary Statement, p. 16.*

Rotation Ages

Jack pine is a relatively short-lived species reaching aturity between 40 and 70 years (fig. 2). Mean annual owth in cords culminates earlier in high density stands an in low density stands (table 8, Appendix). Low ensity stands at older ages – 30 square feet of basal ea per acre or less at age 40 and 60 square feet at age 0 – should be harvested and regenerated because they ill not reach full stocking by age 70. Poor sites will not each high basal area densities at young ages but some ands may be overstocked with numbers of trees per cre, thus requiring weeding or cleaning to avoid agnation.

igure 2. – *This jack pine stand is about 50 years old and has reached the recommended rotation age for pulpwood, however another 20 years is recommended to produce poles and sawtimber.*

On the better sites poles and small sawtimber may be rown with 70-year rotations, especially in stands that re thinned to basal area densities of 80 square feet per cre at 30 to 40 years of age so the trees maintain good iameter growth. Cordwood production is best in the enser stands and may culminate as early as 40 years.

Other factors may require shorter rotations in some tands to reduce the risk of serious losses. Budworm njury, disease attacks, fire scars, or severe weather tresses may indicate rotation ages of 40 years or less. Stands on poor sites are often under more stress than those on the better sites and they usually do not reach merchantable size as early because of slower growth. High risk stands should be harvested at rotation ages of 40 years or as soon as merchantable.

Rotation ages in stands managed primarily for resources other than timber depend on the health and vigor of the stand and the environmental conditions required for the resource. They will not generally be over 70 years as most stands become decadent about that age but they may be any younger age that provides the needed conditions.

Controlling Stand Establishment

Site Evaluation

Jack pine does best on well drained loamy sands but is more common on the dry sandy soils where it is better adapted than most other species. It is also found on eskers, sand dunes, and rocky soils. Jack pine is an intolerant pioneer species that typically colonizes burns and bare mineral soil areas. Successional changes are relatively fast on all but the deep dry sandy soils such as Grayling, Rubicon, Plainfield, Vilas, and Menagha where changes are often so slow that jack pine is sometimes considered the edaphic climax.

In evaluating sites for establishing jack pine stands both the productivity and the site preparation needs should be considered. Productivity of jack pine stands can be estimated from site index curves (fig. 4, Appendix, p. 11) in combination with stand volume tables (table 4 or 6, Appendix, p. 13 & 14). Site preparation needs may also be related to site quality. Generally the higher the site quality the greater the need to control competing sod, shrubs, and trees to favor the establishment of jack pine. On the sites with strong tendencies toward successional change conversion to a more valuable or desirable species such as red pine may be considered.

Site Preparation

Three major objectives of site preparation are (1) treating the slash to reduce the fire hazard and the hindrance to regeneration, (2) controlling shrubs and other competition, and (3) exposing mineral soil seedbeds. One, two, or all three of these objectives may be required, depending on the site conditions (fig. 3).

Figure 3. — *Some kind of site preparation is usually needed after harvesting mature jack pine to dispose of slash, remove unwanted trees and shrubs, and expose mineral soil seedbeds.*

Slash treatments include removing it from the area such as by pushing it aside with a bulldozer and by full-tree skidding, or modifying the slash on the area. Modifying the slash on the area includes prescribed burning, chipping, discing, chopping, and breaking it up with various types of drags. The method of slash treatment should be selected according to the results desired and to fit as many of the other site preparation needs of the area as possible.

Controlling shrubs and other competition may be accomplished while treating the slash or may require another operation. Light shrub cover can be controlled by full-tree skidding, hand-cutting, hand-scalping, or machine scalping such as with furrowing plows and specially designed scalping cultivators. Medium shrub cover may require discing or roller-chopping, and heavy shrub cover often requires bulldozing, shearing, rock raking, root raking, prescribed burning, or the use of herbicides. Combinations of these methods may be needed in some cases to obtain the desired results. Sod competition presents a special problem and should be controlled in conjunction with preparing seedbeds.

The best jack pine seedbeds are bare mineral soil. Seedbeds of mixed humus and mineral soil are generally not as good because roots and seeds in the humus result in increased competition. Prescribed burning leaves a seedbed that is more variable. If the fire is hot enough to consume most of the humus, the seedbed is almost as good as bare mineral soil, but if an inch or so of th humus remains, the seedbed is more like those prepare by mixing the humus and mineral soil. Light fires c spring fires that leave most of the humus unburned d not prepare good seedbeds. Undisturbed humus is als considered a poor seedbed under most condition Differences among the various seedbeds may be sma when weather conditions for germination and surviv are good, but when they are not, seedbeds can determin success or failure. Many kinds of mechanical equipmen can be used to prepare scalped or mixed humus seedbec including most of those described for controlling shrub Prescribed burning should be limited to areas that hav sufficient fuels (including slash) for hot enough fires t prepare good seedbeds.

Silvicultural Systems

Jack pine seedlings require full sunlight to be succes fully established. Clearcutting, seed tree, or shelterwoo silvicultural systems may be appropriate depending o the stand and site conditions.

Clearcutting is the recommended silvicultural syster for harvesting mature trees where a new stand will b established by planting improved seedlings, direct seed ing, or scattering serotinous cones from high qualit trees. Clearcutting may also be appropriate for matur stands that have an understory of fully stocked seedling Some jack pine stands were established by seeding fro the cull trees left on pine-harvested areas and some c the planting stock used in plantations was grown fro seed of other geographic areas and sometimes even fro poor quality open grown trees. If the mature stand is no a suitable seed source for regenerating a new seedlin stand, prescribed burning followed by planting or direc seeding with a desirable seed source should be con sidered. If the tree quality is desirable and the cones ar serotinous, a new seedling stand can be established b scattering cone-bearing branches on bare mineral so seedbeds. The heat near the ground surface will open th cones and release the seed. The branches will provid light beneficial shade during germination but care needed to avoid accumulations of slash that migh interfere with later seedling development or present fire hazard during the most vulnerable seedling stage c development.

The seed tree system is recommended as a possib alternative for stands that have 10 well-distribute desirable quality seed trees per acre with an abundar supply of serotinous cones. Prescribed burning is recon mended to consume the slash, kill the competitio

prepare favorable seedbeds, and open the serotinous cones on the seed trees to seed the area. Careful selection of high quality seed trees can improve the quality of the seedling stand. It is important to burn the slash soon after harvesting to minimize the risk of losing seed trees by windthrow before the cones are opened by the fire and the seeds dispersed. Jack pine slash requires about a month of warm, dry weather to cure adequately for effective burning. Early spring fires will result in seeding at the most favorable season but late fall fires may be almost as effective if the seed overwinters safely for early spring germination. If weather conditions following seed dispersal are unfavorable for seedling establishment, direct seeding or planting may be required as the seed trees will have been killed by the fire.

The shelterwood system is recommended only for vigorous, well stocked stands with 30 to 40 square feet of basal area per acre in desirable quality trees with nonserotinous cones that can be left after the regeneration cut to seed the area. Site preparation as discussed under "Site Evaluation" is an important requirement to assure seedling establishment. The removal cut should be made as soon as the seedling stand has 60 percent milacre stocking or within 10 years. Prompt removal of the shelterwood overstory will minimize volume losses due to mortality following the regeneration cut, seedling losses due to logging damage and suppression, and will reduce the risk of budworm buildup in the overstory and subsequent defoliation of seedlings.

Conversion

Jack pine is a pioneer, temporary type on nearly all sites except the dry sandy soils. Successional forces generally increase as site quality increases adding to the difficulty of maintaining jack pine on better sites. Many of the other species that are better adapted to these sites are also more productive and more valuable. On such areas jack pine should be converted to another forest type at the end of the rotation.

In mixed stands the conversion may be accomplished gradually by harvesting the jack pine in several cuts if the more desirable species have sufficient stocking. If there is insufficient stocking of the other species or the stand is essentially pure, jack pine should be converted by clearcutting and planting either red pine or white spruce, depending on the site.

Seeding and Planting

In areas where favorable soil moisture conditions can be expected as a result of a water table within a few feet of the surface, or frequent precipitation during the period of germination and early seedling development, it will be possible to establish a seedling stand by direct seeding repellent-treated seed. Seed should be coated with bird and rodent repellents (such as Arasan) and sown at the rate of 20,000 viable seeds per acre (about 3 ounces) early in the spring to take advantage of snowmelt waters for germination. Although jack pine is one of the most successful species for direct seeding, failures can be expected if precipitation is lacking for more than a few days during seed germination or more than a week during early seedling establishment, especially on the droughty soils. Usually the seedbeds on these sites will be suitable for reseeding the second or third year if unusually poor weather conditions cause the first seeding to fail.

Some areas that have been unsuccessfully seeded will require planting as will many areas with deep, dry sandy soils. Bare root stock should be planted only in the spring but container-grown stock can be planted in the summer as well. About a 6- to 8-foot spacing is usually recommended for jack pine.

OTHER RESOURCE CONSIDERATIONS

Recreation

Jack pine stands can be an important part of the visual resource for recreation. Harvesting, site preparation, and regeneration practices make major changes in the appearance of an area and require careful planning and execution to ultimately achieve the esthetic appeal that is desired. The size and shape of harvested areas can be very effective in improving the overall appearance of some areas if they are tailored to the general surroundings. Good workmanship and cleanup are musts to improve the recreational values on any area. On developed recreation areas we recommend that jack pine be gradually converted to a species that is less sensitive to disturbance and longer lived.

Opportunities for blueberry picking, an activity enjoyed by many people, may be increased on some jack

pine areas during the regeneration period, especially if site preparation methods – such as prescribed burning or scarification – prune the tops of blueberry bushes without damaging their roots so that vigorous new shoots develop to produce large crops of blueberries.

Water

Management of jack pine stands that cover only a part of a watershed should be coordinated with management of other areas in that watershed to maintain even annual flows of high quality water. Forests that cover whole watersheds will minimize seasonal fluctuations and stabilize annual flows when they are fully regulated. Care is needed in harvesting trees near streams and lakes to prevent soil and debris from getting into the water. Some stream crossings may require culverts. Careful planning of landings and trails should keep stream crossings to a minimum. Heavy equipment should be kept away from shorelines and stream banks to prevent soil from eroding into the water. Trees should be felled away from the water and winched when necessary to the nearest skid trail. Intermittent stream channels should not be used for skidding. Timber harvesting when soils are frozen will reduce erosion hazards on some areas.

Wildlife

Jack pine is generally considered a medium preference deer food, the same as aspen. Young trees may be heavily browsed where deer populations are high. Dense sapling and pole stands offer some wind protection and winter shelter but generally jack pine stands do not provide as good winter shelter as most other conifers. Because older stands of jack pine are usually less dense than other conifers, the understory shrubs and herbaceous plants have better growth and thus provide a better food supply.

Some wildlife species benefit from special stand conditions such as the excellent cover that dense young stands of jack pine provide for hares. Clumpy stands of young trees with branches reaching the ground provide nesting sites for the endangered Kirtland's Warbler in the Lower Peninsula of Michigan. Most wildlife species that find food or shelter in jack pine forests will benefit from management efforts to provide a good distribution of age classes.

APPENDIX
Site Index, Stocking

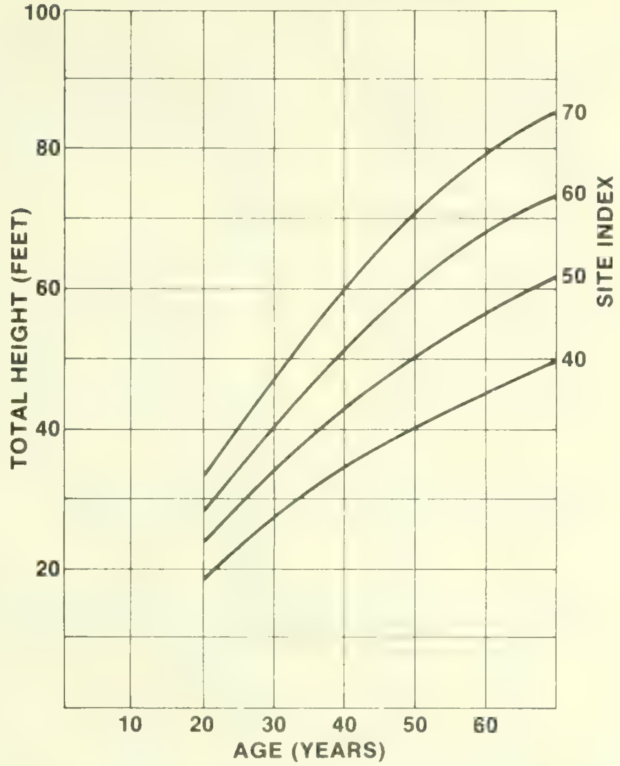

Figure 4. – *Jack pine site index curves. Based on the equation by Lundgren and Dolid (1970): height = 1.633 (site index) (1 - e* $^{-0.02233\,(age)}$*)* $^{1.2419}$.

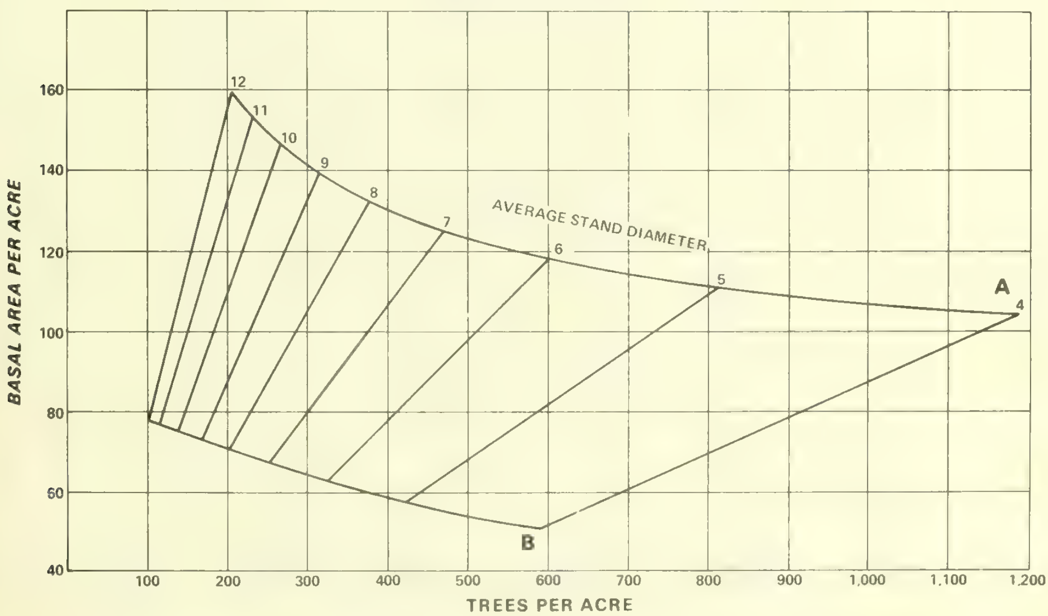

Figure 5. – *Stocking chart for jack pine stands. Recommended upper limit (A curve) is based on stand tables from Eyre and LeBarron (1944) and adjusted to approximately 85 percent stocking for poletimber and 100 percent stocking for sawtimber stands. Minimum stocking (B curve) is based on crown width for open-grown trees from Bella (1967).*

Growth and Yield

Table 1. *Estimated average d.b.h. in 20-year-old jack pine stands*

Site index	Number of trees per acre: 500	1000	1500	2000
Feet	*Inches*			
70	4.4	4.0	3.7	3.3
60	3.8	3.4	3.1	2.9
50	3.2	2.9	2.6	2.4
40	2.5	2.3	2.1	1.9

Source: Laidly, Paul. 1976. Unpublished analysis of jack pine growth studies at the Northern Conifers Laboratory, Grand Rapids, Minnesota.

Table 2. – *Estimated basal area per acre in 20-year-o[ld] jack pine stands*

Site index	Number of trees per acre: 500	1000	1500	2000
Feet	*Square feet*			
70	53	87	112	119
60	39	63	79	92
50	28	46	55	63
40	17	29	36	39

Source: Laidly, Paul. 1976. Unpublished analysis of jack pine growth studies at the Northern Conifers Laboratory, Grand Rapids, Minnesota.

Table 3. – *Current annual basal area growth per acre*[1] *for jack pine stands by site, age, and stand density*

Total age	Total height	Stand density basal area per acre: 30	60	90	120	150
Years	*Feet*	*Square feet*				
SITE INDEX 70						
20	32	3.8	4.9	5.0	4.1	--
30	47	2.1	2.8	2.8	2.3	1.2
40	59	1.4	1.8	1.9	1.5	.8
50	70	1.0	1.3	1.4	1.1	.6
60	78	.8	1.1	1.1	.9	.5
70	85	.7	.9	.9	.7	.4
SITE INDEX 60						
20	28	3.4	4.5	4.6	--	--
30	40	1.9	2.5	2.6	2.1	--
40	51	1.3	1.6	1.7	1.4	.7
50	60	.9	1.2	1.2	1.0	.5
60	67	.7	1.0	1.0	.8	.4
70	73	.6	.8	.8	.7	.4
SITE INDEX 50						
20	23	3.1	4.0	--	--	--
30	34	1.7	2.2	2.3	--	--
40	42	1.1	1.5	1.5	1.2	--
50	50	.8	1.1	1.1	.9	.5
60	56	.7	.9	.9	.7	.4
70	61	.6	.7	.7	.6	.3
SITE INDEX 40						
20	18	2.7	--	--	--	--
30	27	1.5	1.9	1.3	--	--
40	34	1.0	1.3	1.3	--	--
50	40	.7	.9	1.0	.8	--
60	45	.6	.8	.8	.6	.3
70	49	.5	.6	.6	.5	.3

[1]Based on the equation: current annual basal area growth per acre = 0.276 (site index)$^{-0.63}$ Exp (-4 Exp (-29.18/Age)) (1 + 0.56 (basal area) - 0.00358 (basal area)^2).

Source: Laidly, Paul. 1976. Unpublished analysis of jack pine growth studies at Northern Conifers Laboratory, Grand Rapids, Minnesota.

able 4. – *Volume in cubic feet*[1] *per acre for jack pine stands by site, age, and stand density*

Total Age	Total height	Stand density - basal area per acre: 30	60	90	120	150
Years	*Feet*	*Cunits (100 cubic feet) per acre*				
		SITE INDEX 70				
20	32	3.9	7.8	11.8	15.7	--
30	47	5.7	11.5	17.3	23.0	28.8
40	59	7.2	14.5	21.7	28.9	36.2
50	70	8.6	17.2	25.7	34.3	42.9
60	78	9.6	19.1	28.7	38.2	47.8
70	85	10.4	20.8	31.2	41.7	52.1
		SITE INDEX 60				
20	28	3.4	6.9	10.3	--	--
30	40	4.9	9.8	14.7	19.6	--
40	51	6.2	12.5	18.8	25.0	31.2
50	60	7.4	14.7	22.1	29.4	36.8
60	67	8.2	16.4	24.6	32.8	41.1
70	73	8.9	17.9	26.8	35.8	44.7
		SITE INDEX 50				
20	23	2.8	5.6	--	--	--
30	34	4.2	8.3	12.5	--	--
40	42	5.1	10.3	15.4	20.6	--
50	50	6.1	12.3	18.4	24.5	30.6
60	56	6.9	13.7	20.6	27.4	34.3
70	61	7.5	15.0	22.4	29.9	37.4
		SITE INDEX 40				
20	18	2.2	--	--	--	--
30	27	3.3	6.6	--	--	--
40	34	4.2	8.3	12.5	--	--
50	40	4.9	9.8	14.7	19.6	--
60	45	5.5	11.0	16.5	22.1	27.6
70	49	6.0	12.0	18.0	24.0	30.0

[1]Gross cubic-foot peeled volume entire stems of all trees based on equation:
Volume = .4085 (basal area x height).
Source: Buckman, Robert E. 1961.

Table 5. – *Current annual cubic foot growth*[1] *per acre for jack pine stands by site, age, and stand density*

Total age	Total height	Stand density - basal area per acre: 30	60	90	120	150
Years	*Feet*	*- - - - - Cubic feet - - - - - -*				
		SITE INDEX 70				
20	32	72	106	127	135	--
30	47	59	90	107	114	110
40	59	48	71	87	91	87
50	70	40	60	74	76	73
60	78	36	55	65	68	65
70	85	32	46	54	54	51
		SITE INDEX 60				
20	28	57	86	103	--	--
30	40	47	71	88	94	--
40	51	40	58	73	79	76
50	60	32	49	59	64	61
60	67	28	45	53	56	54
70	73	24	36	42	46	43
		SITE INDEX 50				
20	23	44	66	--	--	--
30	34	37	56	70	--	--
40	42	29	46	56	60	--
50	50	25	40	49	53	53
60	56	22	33	39	41	40
70	61	20	27	32	35	32
		SITE INDEX 40				
20	18	32	--	--	--	--
30	27	27	41	--	--	--
40	34	21	33	40	--	--
50	40	18	27	35	38	--
60	45	16	25	30	31	30
70	49	15	22	27	30	30

[1]Based on the following equation: gross cubic-foot peeled volume growth entire stems of all trees = .4085 (basal area growth x height + height growth x basal area + basal area growth x height growth).

Table 6. – *Volume in cords per acre[1] for jack pine stands by site, age, and stand density*

Total age	Total height	Stand density – basal area per acre: 30	60	90	120	150
Years	*Feet*	- - - - - - -	-	*Cords*	-	- - - - - - -
SITE INDEX 70						
30	47	5.6	11.2	16.7	22.3	--
40	59	7.0	14.0	21.0	28.0	35.0
50	70	8.3	16.6	24.9	33.2	41.6
60	78	9.3	18.5	27.8	37.0	46.3
70	85	10.1	20.2	30.3	40.4	50.5
SITE INDEX 60						
30	40	4.7	9.5	14.2	--	--
40	51	6.1	12.1	18.2	24.2	--
50	60	7.1	14.2	21.4	28.5	35.6
60	67	8.0	15.9	24.0	31.8	39.8
70	73	8.7	17.3	26.0	34.7	43.3
SITE INDEX 50						
40	42	5.0	10.0	15.0	--	--
50	50	5.9	11.9	17.8	23.7	--
60	56	6.6	13.3	19.9	26.6	33.2
70	61	7.2	14.5	21.7	29.0	36.2
SITE INDEX 40						
40	34	4.0	8.1	--	--	--
50	40	4.7	9.5	14.2	--	--
60	45	5.3	10.7	16.0	21.4	--
70	49	5.8	11.6	17.5	23.3	29.1

[1]Based on the equation: Volume = .003958 (basal area x height). Includes gross cordwood volume in rough cords of all stems per acre 3.6 inches d.b.h. and larger to a variable top d.i.b. of not less than 3 inches.

Source: Buckman, Robert E. 1961.

Table 7. – *Current annual cordwood growth[1] per acre for jack pine stands by site, age, and stand density*

Total age	Total height	Stand density – basal area per acre: 30	60	90	120	150
Years	*Feet*	- - - - - - -	-	*Cords*	-	- - - - - - -
SITE INDEX 70						
30	47	0.6	0.9	1.0	1.1	--
40	59	.5	.7	.8	.9	.8
50	70	.4	.6	.7	.7	.7
60	78	.3	.5	.6	.7	.6
70	85	.3	.4	.5	.5	.5
SITE INDEX 60						
30	40	.5	.7	.8	--	--
40	51	.4	.6	.7	.8	--
50	60	.3	.5	.6	.6	.6
60	67	.3	.4	.5	.5	.5
70	73	.2	.4	.4	.4	.4
SITE INDEX 50						
40	42	.3	.4	.5	--	--
50	50	.2	.4	.5	.5	--
60	56	.2	.3	.4	.4	.4
70	61	.2	.3	.3	.3	.3
SITE INDEX 40						
40	34	.2	.3	--	--	--
50	40	.2	.3	.3	--	--
60	45	.2	.2	.3	.3	--
70	49	.1	.2	.3	.3	.3

[1]Based on the equation: Cordwood growth = .003958 (basal area growth x height + height growth x basal area + basal area growth x height growth). Includes gross cordwood growth in rough cords of all stems per acre 3.6 inches d.b.h. and larger to a variable top d.i.b. of not less than 3 inches.

Table 8. – *Recommended rotation ages for jack pine stands without future thinnings by present stand age and density; and mean annual growth in cords for the recommended rotations by site index*

Present age	Present stand density – basal area per acre (square feet): 30	60	90	120
ROTATION AGE				
Years	- - - - - -	*Years*	- - - - - -	
20	70	60	50	40
30	70	70	50	40
40	--	70	60	50
50	--	--	70	60
MEAN ANNUAL GROWTH				
SITE INDEX 70				
	- - - - - -	*Cords*	- - - - - -	
20	0.6	0.7	0.8	0.9
30	.4	.6	.7	.8
40	--	.5	.6	.7
50	--	--	.5	.7
SITE INDEX 60				
20	.5	.6	.7	--
30	.3	.5	.6	.7
40	--	.4	.5	.6
50	--	--	.4	.6
SITE INDEX 50				
20	.4	.5	--	--
30	.3	.4	.5	--
40	--	.3	.4	.5
50	--	--	.4	.5
SITE INDEX 40				
20	.3	--	--	--
30	.2	.3	--	--
40	--	.2	.3	--
50	--	--	.3	.4

[1]Calculated from basal area growth equation (table 3) and cordwood volume equation (table 6). Rough cords for trees 3.6 inches d.b.h. and larger to a 3-inch top d.i.b.

Metric Conversion Factors

convert	to	Multiply by
res	Hectares	0.405
ard feet[1]	Cubic meters	0.005
ard feet/acre[1]	Cubic meters/hectare	0.012
ains	Meters	20.117
rds[1]	Cubic meters	2.605
rds/acre[1]	Cubic meters/hectare	6.437
bic feet	Cubic meters	0.028
bic feet/acre	Cubic meters/hectare	0.070
grees Fahrenheit	Degrees Celsius	[2]
et	Meters	0.305
llons	Liters	3.785
llons/acre	Liters/hectare	9.353
ches	Centimeters	2.540
les	Kilometers	1.609
les/hour	Meters/second	0.447
mber/acre	Number/hectare	2.471
nces	Grams	28.350
nces/acre	Grams/hectare	70.053
unds	Kilograms	0.454
unds/acre	Kilograms/hectare	1.121
unds/gallon	Kilograms/liter	0.120
uare feet	Square meters	0.093
uare feet/acre	Square meters/hectare	0.230
ns	Metric tons	0.907
ns/acre	Metric tons/hectare	2.242

[1]The conversion of board feet and cords to cubic ters can only be approximate; the factors are based an assumed 5.663 board feet (log scale) per cubic ot and a cord with 92 cubic feet of solid material.

[2]To convert °F to °C, use the formula 5/9 (°F-32) $\frac{°F-32}{1.8}$.

Common and Scientific Names of Plants and Animals

Common name	*Scientific name*
Plants	
Aspen, bigtooth	*Populus grandidentata*
quaking	*Populus tremuloides*
Birch, paper	*Betula papyrifera*
Blackberries	*Rubus occidentalis*
Blueberries	*Vaccinium spp.*
Comandra rust	*Cronartium comandrae*
Eastern gall rust	*Cronartium quercuum*
Fir, balsam	*Abies balsamea*
Hazel	*Corylus spp.*
Juneberries	*Amelanchier spp.*
Maple, red	*Acer rubrum*
sugar	*Acer saccharum*
Oak, bur (scrub)	*Quercus macrocarpa*
no. pin	*Quercus ellipsoidalis*
no. red	*Quercus rubra*
Pine, jack	*Pinus banksiana*
red	*Pinus resinosa*
white	*Pinus strobus*
Prickley ash	*Xanthoxylum americanum*
Raspberries	*Rubus strigosus*
Root rot	*Armillarea mellia*
Roses	*Rosa spp.*
Spruce, black	*Picea mariana*
white	*Picea glauca*
Stalactiform rust	*Cronartium coleosporioides*
Sweetfern	*Comptonia peregrina*
Sweetfern rust	*Cronartium comptoniae*
Tar spot needle cast	*Davisomycella ampla*
Western gall rust	*Peridermium harknessii*
Animals	
Bark bettle	*Ips pini*
Deer	*Odocoileus virginianus*
Eastern pine shoot moth	*Eucosma sonomana*
Hare	*Lepus americanus*
Jackpine budworm	*Choristoneura pinus*
Kirtland's Warbler	*Dendroica kirtlandii*
Mice	*Microtus pennsylvanicus*
Pine chafer beetle	*Anomala oblivia*
Pine root collar weevil	*Hylobius radicis*
Pine tip moth	*Rhyacionia adana*
Pine tortoise scale	*Toumeyella numismaticum*
Pine tussock moth	*Dasychira plagiata*
Pine webworm	*Tetralopha robustella*
Pitch nodule maker	*Petrova albicapitana*
Porcupine	*Erethizon dorsatum*
Root tip weevil	*Hylobius spp.*
Sawflies	*Neodiprion spp.*
White pine weevil	*Pissodes strob.*
Zimmerman pine moth	*Dioryctria zimmermani*

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key – out of the reach of children and animals – and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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Plant a tree...trees give oxygen.

manager's handbook for

RED PINE IN THE NORTH CENTRAL STATES

ENERAL TECHNICAL REPORT NC-33
RTH CENTRAL FOREST EXPERIMENT STATION FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

Other Manager's Handbooks are:

Jack pine – GTR-NC-32
Black spruce – GTR-NC-34
Northern white-cedar – GTR-NC-35
Aspen – GTR-NC-36
Oaks – GTR-NC-37
Black walnut – GTR-NC-38
Northern hardwoods – GTR-NC-39

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CONTENTS

FOREWORD

This is one of a series of manager's handbooks for important forest types in the north central States. The purpose of this series is to present the resource manager with the latest and best information available on handling these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. However, ways to modify management practices to maintain or enhance other values are included where sound information is available.

The author has, in certain instances, drawn freely on unpublished information provided by scientists and managers outside his specialties. He is also grateful to the several technical reviewers in the region who made many helpful comments.

The handbooks have a similar format, highlighted by a "Key to Recommendations". Here the manager can find in logical sequence the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbook. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objectives. The manager should also apply new research findings as they become available so that the culture of these important forest types can be continually improved.

RED PINE
IN THE NORTH-CENTRAL STATES

John W. Benzie, *Principal Silviculturist*
Grand Rapids, Minnesota

SILVICAL HIGHLIGHTS

A century ago red pine[1] made up about a third of the 2 million acres of pine forests in Minnesota, Wisconsin, ıd Michigan; today it covers only a little more than 1 illion acres – mostly acreage planted since 1930.

Red pine on the drier sites grows in pure stands and in ixtures with jack pine, aspen, paper birch, and scrub ıks; on the more moist sites with white pine, red aple, red oak, balsam fir, and white spruce. Red pine ows best on well drained sandy to loamy soils but the ee is most common on sandy soils where site index ay range from 45 to 75 feet at 50 years of age.

Red pine is shade intolerant and long-lived; some ands reach 200 years of age, and some individual trees ɔout 400 years, but commercial rotation ages are generally between 60 and 120 years. Red pine often succeeds its less tolerant and shorter-lived associates such as jack pine, paper birch, and the aspens; in turn it is succeeded by its more shade tolerant associates that regenerate in the understory more easily. Wildfires occasionally disrupt ecological succession and a few thick-barked, old-growth trees usually survive to establish a pure seedling stand or a mixed stand of red pine and other intolerant species.

Seed production in mature red pine is irregular; heavy crops occur at intervals of 10 years or more. Red pine phenotypes are very homogenous showing little variation over the entire range. In some localities red pine suffers losses from diseases, insects, mammals, and weather, but it generally has fewer natural enemies than its associated species.

MANAGEMENT OBJECTIVES AND NEEDS

Management objectives considered in this handbook e to control the establishment, composition, and owth of red pine forest stands so that intermediate innings will provide useful products such as pulpwood, osts, poles, cabin logs, piling, and small sawtimber, and ıe final harvest will yield high quality sawtimber and eneer. The management of red pine forest stands ıroughout their rotation for other uses such as recreaon, wildlife habitat, and watersheds is also covered and ıggestions are given for increasing these benefits.

Although it is possible to grow red pine in either ven-aged or uneven-aged stands, even-aged silvicultural systems give better results because red pine grows best in full sunlight.

Red pine seed crops are too variable to depend on for natural regeneration, so seed must be collected during good seed years for direct seeding, growing container seedlings, or growing bare root planting stock. Seedling establishment requires site preparation on areas where slash or vegetation, particularly sod or shrubs, covers the seedbed or planting site. Red pine seedlings often require tending for several years after they are established to release them from regrowth of competing vegetation and protect them from damage by fire, insects, and disease.

Periodic thinning of young stands is recommended to put the growth on the best trees available, maintain

[1] *For scientific names of plants and animals, see* *ppendix, p. 20.*

uniform growth rates, remove diseased and injured trees, shorten rotations, and increase the yield. Considerable flexibility in rotation age, with only slightly lower yields, provides opportunities to adjust age classes, extend rotations on areas where big trees are important, or harvest stands early to meet changing needs.

To help meet projected needs for softwood sawtimber the red pine type should be restored as soon as possible on several million acres of the more than 10 million acres in the Lake States that converted to other cover types after the original pine logging. Improved systems for site preparation, seedling establishment, and control of species composition are needed so that conversion can be done more efficiently and can be more effective for other uses such as recreation and wildlife habitat during the period of stand establishment.

KEY TO RECOMMENDATIONS

The following key is based primarily on the technical aspects of forest management – silviculture, protection, and regulation. The administrative aspects – economic, legal, and social – have only limited influence in the key so the user is cautioned to evaluate these aspects carefully when applying the technical recommendations.

The key recommends management practices for some of the common site and stand conditions encountered in the red pine type or on potential red pine sites. Use of the key in conjunction with a stand examination will lead to one or more general recommendations. Each recommendation refers to the appropriate section under "Management Considerations" where optional silvicultural tools and methods are discussed.

To use the key, start with the first pair of numbered statements. Choose the statement that best describes the situation and find either a number only, a recommendation and a number, or a recommendation only. If a number is given, find the pair of statements with that number and continue the process until a recommendation only is reached. All recommendations encountered in going through the key should be considered in your prescription.

1. **Red pine stand** . . . .
   See "Stand Conditions–Type", p. 3
1. **Other stands or the area is nonstocked** . . . .
   2. **Even-aged stand** . . . .
      See "Stand Conditions–Age", p. 4
   2. **Uneven-aged stand** . . . .
3. **Stand has minimum or higher stocking** . . . .
   See "Stand Density", p. 4 and fig. 1, Appendix
3. **Stand is below minimum stocking** . . . .
   4. **Stand is not mature** . . . .
      See "Rotation Ages", p. 8
   4. **Stand is mature** . . . .
5. **Average tree d.b.h. is less than 2 inches** . . . .
   See "Stand Conditions–Size", p. 4
5. **Average tree d.b.h. is 2 inches or more** . . . .
   6. **400 or more trees per acre free to grow** . . . .
      See "Release", p. 5
   6. **Less than 400 trees per acre free to grow** . . . . RELEASE .
7. **Less than 2,000 trees per acre** . . . .
   See "Weeding and Cleaning", p. 6
7. **2,000 or more trees per acre** . . . . WEED . .
   8. **Average tree d.b.h. is less than 5 inches** . . . .
      See "Stand Conditions–Size", p. 4
   8. **Average tree d.b.h. is 5 inches or more** . . . .

9. **Basal area is less than 160 square feet per acre** . . . 17
See "Weeding and Cleaning", p. 6

9. **Basal area is 160 square feet or more per acre** . . . CLEAN . . 17

10. **Basal area is less than 140 square feet per acre** . . . 11
See "Thinning", p. 7

10. **Basal area is 140 square feet or more per acre** . . . THIN . . 11

11. **Crop trees do not need pruning** . . . 17
See "Pruning", p. 7

11. **Crop trees need pruning** . . . PRUNE . . 17

12. **Old growth stands are needed for timber or other resources** . . . 13
See "Regulating the Forest", p. 7, and "Other Resource Conditions", p. 12

12. **Old growth stands are not needed** . . . 18

13. **Temporary need until other stands mature** . . . EXTEND ROTATION . . 17
See "Maintaining Old Growth Stands", p. 8, and "Harvesting Methods", p. 8

13. **Continuing need for mature trees on area** . . . USE SELECTION

14. **Site is suitable for red pine** . . . 15
See "Site Evaluation", p. 9

14. **Site is not suitable for red pine** . . . MANAGE FOR OTHER SPECIES

15. **No merchantable stand on area** . . . 16
See "Conversion Opportunities", p. 9

15. **Merchantable stand on area** . . . USE CLEARCUT . . 19

16. **Will have merchantable stand in 20 years or less** . . . 17
See "Productivity", p. 5

16. **Will not have merchantable stand in 20 years** . . . 19

17. **Low risk of injury or loss** . . . WAIT
See "Risk", p. 4, and "Quality", p. 5

17. **High risk of injury or loss** . . . CONTROL IF FEASIBLE

18. **Continuous tree cover needed** . . . USE STRIP SHELTERWOOD . . 19
See "Harvesting Methods", p. 8

18. **Continuous tree cover not needed** . . . CLEARCUT . . 19

19. **Adequate mineral soil seedbeds free of slash and competition** . . . 20
See "Site Preparation", p. 10

19. **Inadequate seedbeds** . . . PREPARE SITE . . 20

20. **Easy seeding chance** . . . DIRECT SEED
See "Seeding and Planting", p. 10

20. **Poor seeding chance** . . . PLANT

TIMBER MANAGEMENT CONSIDERATIONS

Stand Conditions

Red pine stands and potential red pine sites need to be carefully examined on the ground to best determine their condition, but use of aerial photos, maps, and other sources of information should not be overlooked. The stand – or site – condition, which is the basis for recommendations, includes type, age, size, density, risk, quality, productivity, and operability.

Type

The red pine type includes both pure red pine stands and various mixtures in which red pine is the predominant species. In addition to the species composition of the main stand, important understory tree or shrub species should be evaluated for site preparation needs and multiple use values. Nonstocked areas, poorly stocked red pine stands, and other forest types may be suitable sites to establish red pine seedlings.

Age

The age of dominant and codominant trees in even-aged stands will aid in estimating site productivity and comparing the present stand with its potential condition. Total age in red pine can be estimated by adding 8 years to age at breast height (4.5 feet above ground). Rotation ages for red pine are discussed on page 8. In uneven-aged stands, the distribution of age classes will help determine the feasibility of using the selection system. Uneven-aged stands should have three or more age classes separated by 20 years or more and will require extra effort to establish new age classes periodically by seeding or planting. Uneven-aged management of stands is not recommended except for special areas where a continuing need for mature trees will justify the extra effort required.

Size

Even-aged stands are classified as seedling stands (up to 2 inches average d.b.h.), sapling (2 to 5 inches), pole (5 to 9 inches), and sawtimber (9 inches and over). Tree diameters are strongly influenced by stand density as well as age and site (table 2, p. 15, Appendix). In managed stands with more uniform stand density, tree size will also be more uniform.

The optimum distribution of tree sizes for uneven-aged red pine stands has not been determined so records should be maintained to help control recruitment into each size class on the special areas where uneven-aged management is needed.

Stand Density

Two important aspects of stand density in even-aged stands are the stocking level and uniformity. As the stocking level decreases toward the minimum stocking, uniformity or distribution of the trees in the stand increase in importance. The minimum stocking in basal area and number of trees for perfectly uniform stands of various average stand diameters was calculated from the maximum amount of growing space trees of each diameter could use (fig. 7, p. 13, Appendix). Minimum stocking for stands averaging 5 inches in diameter is about 400 trees and 60 square feet of basal area per acre. In stands averaging 15 inches in diameter minimum stocking is about 80 trees and 100 square feet of basal area per acre. The recommended upper limit of stocking for managed stands is based on 80 percent of a normal yield table for pole stands (5 to 9 inches average diameter) and the crown diameters of forest grown trees for sawtimber stands (fig. 7, p. 13, Appendix). The recommended upper limit of stocking for managed stands averaging 5 inches in diameter is about 1,100 trees and 150 square feet of basal area per acre. For stands averaging 15 inches in diameter it is 175 trees and 215 square feet of basal area per acre.

Seedling and sapling stands (less than 5 inches average diameter) should have between 400 and 1,100 trees per acre. Fewer than 400 trees will not provide minimum recommended stocking by the time the stand reaches pole-timber size and more than 1,100 trees will exceed the upper limit of recommended stocking before the trees reach pole-timber size and can be thinned commercially.

Stand density guides for uneven-aged red pine stands have not been determined but in general the seedlings need to outnumber the saplings which in turn outnumber the pole trees which outnumber the sawtimber trees. Losses in the smaller size classes are expected and considerable effort will be needed to assure survival and growth of enough trees in each class to replace those harvested, lost, or moving up into the next larger class.

Risk of Loss from Damaging Agents

Risk depends on the degree of injury and the chance for the tree to recover from damage by disease, insects, animals, fire, or weather. Weather damage includes flooding, drought, ice and snow breakage, and lightning strikes.

A couple of diseases that have caused problems in young red pine are Scleroderris canker and red pine shoot blight. Other diseases include root rots, butt rots and needle blights that may be important in local areas. Best control measures are to remove infected trees and provide favorable growing conditions for red pine crop trees to maintain their vigor.

Several insects may defoliate red pine including a number of sawflies, the pine tussock moth, jack pine budworm, and pine webworm. Damage to tips and buds may be caused by the European pine shoot moth, the Zimmerman pine moth, or occasionally by the white pine weevil. The Saratoga spittlebug may cause mortality of branches and entire seedlings by mechanical injury from feeding on the sap. Other insects that sometimes injure red pine are white grubs, pine root collar weevil, and bark beetles.

Insect control may involve removal of alternate host plants as in the case of sweetfern to control the Saratoga spittlebug; modifying the habitat such as pruning the lower branches to control the European pine shoot moth, and removing the duff to control the pine root collar weevil; or in some cases by using chemicals[2] to protect the trees. An entomologist should be consulted for recommended control measures.

Animal injury to red pine may be caused by deer, hare, porcupine, or mice in local areas. Measures short of animal control may not be sufficient but eliminating protective grass and shrub cover will help reduce hare and mice activity in the area.

Trees with large fire scars may be a risk for wind breakage and decay. They should be salvaged in one of the thinning operations. Young stands are susceptible to fire injury and should be protected with a fire break. A narrow strip of deciduous trees that are less flammable than red pine can be used to break up large blocks of pine. Pruned trees will reduce the risk of ground fires crowning in sapling stands. In pole-size and larger timber periodic understory burning can control build-up of fine fuels and help reduce the risk of wildfire.

Quality

Red pine tree quality is related to size, form, straightness, and a clean bole. In managed stands the poorer quality trees should be removed in the periodic thinnings favoring the best quality crop trees. Even-aged stands managed near the recommended upper limit of stand density will have less taper, smaller branches, and a greater number of trees from which to select the final crop trees. Crop trees should be low risks, free of defects, and vigorous. Stands should have 100 to 150 acceptable crop trees per acre. Clean boles can be obtained by pruning.

Productivity

Site index is used to estimate productivity of the site (see p. 9 and fig. 8, Appendix) but the productivity of the stand depends not only on the site but how well it is being used. The productivity of a stand can be estimated with the aid of the growth and yield tables in the Appendix. Yields in cubic feet, cords, and board feet are shown for site indices 45, 55, 65, and 75 feet at several different ages and for stand densities of 30, 60, 90, 120, 150, and 180 square feet of basal area per acre (tables 5, 7, and 9, Appendix). Current annual growth is also shown for these same stand conditions so that growth of any stand can be projected for the next growth period (tables 6, 8, and 10, Appendix). If projections are made for more than 10 years, it would be best to interpolate a new current annual growth from the table or use the equations given in the table to compute the periodic annual growth for the period.

Operability

Markets, access, and volume of products that can be removed in a thinning or final harvest determine operability. The minimum volume required depends to a large extent on the value of the product so that managing a stand for higher value products will usually make it operable with lower volumes. Harvested volume per landing is more important than the volume per acre in determining operability. One landing of about 1/2 acre is recommended for up to 40 acres in managed stands. Although 40 acres is the recommended area for establishing new stands on large forest ownerships, minimum size for general forest management is 10 acres. Smaller areas can be managed to meet special needs or owner's objectives but costs will usually be higher.

Controlling Composition and Growth

Red pine trees grow best in full sunlight; that is, they are intolerant of overhead shade. In mixed stands with species less tolerant than red pine such as jack pine and aspen, red pine growth is reduced by the shading from the trees that have faster height growth as seedlings and saplings. In mixed stands with more tolerant species red pine may be crowded out by the severe competition. Cultural practices can be used to keep the red pine crop trees free from overhead shade and to provide the needed growing space for rapid growing, high quality trees.

Release

Complete release of red pine seedlings from shrubs and other low competition may be needed by the end of the third growing season. Cutting by hand requires a lot of labor and regrowth of the competition may necessitate several cuttings at 2- or 3-year intervals. The most practical release method where there are more than just a few trees or shrubs is chemical control with broadcast foliage sprays.

Two of the most useful herbicides are 2,4-D and 2,4,5-T. These two chemicals can control most of the

[2] *See Pesticide Precautionary Statement, p. 21.*

deciduous woody competition without injuring red pine if spraying is done soon after pine leader growth is complete and the terminal bud is set, around mid-July. Spraying should be completed before the middle of August for best control of hardwoods. Most of the common competing species can be controlled with 2,4-D but blackberries, raspberries, roses, juneberries, prickly ash, oaks, and maples are resistant to it. All of these species except the maples can be controlled with 2,4,5-T. Maples are difficult to control with foliar sprays but felling the tree and spraying the stump with chemicals containing 2,4,5-T is effective. The use of chemical herbicides requires strict adherance to label instructions.[2]

Planting red pine under hardwood overstories is not recommended because serious growth losses occur with even a light overstory (fig. 9, Appendix). Plantations with hardwood overstory should be released as soon as possible (fig. 1). Merchantable overstory trees may be harvested and unmerchantable trees felled, girdled, or poisoned. Chemicals can be sprayed on the lower 2 feet of the bole on trees up to 3 inches in diameter, injected into frill girdles or basal cuts on larger trees, or sprayed on the foliage as done for control of low competition.

Figure 1. — *Red pine trees need complete release from overhead shade for best growth.*

Weeding and Cleaning

Seedling stands with over 2,000 trees per acre a sapling stands that have over 160 square feet of ba area per acre should be weeded or cleaned by precommercial thinning. Weeding is done during t seedling stage of stand development and cleaning duri the sapling stage. These operations provide adequa growing space for the potential crop trees and mainta their rapid diameter growth. Red pine stands that ha been established by natural seeding, direct seeding, planting at close spacings will usually benefit from the operations.

Clearing strip roads about 12 feet wide at intervals 50 to 60 feet will provide access into the stand f weeding, cleaning, and future thinnings (fig. 2). seedling stands (less than 2 inches average diamete having more than 2,000 trees per acre, at least 1(potential crop trees per acre should be given a minimu growing space of 25 square feet each. Up to half of t crop trees may be located along the strip roads and t other half should be between them at approximate 20-foot spacings.

Densely stocked sapling stands (2 to 5 inches avera diameter) with 160 square feet of basal area or more p acre should be cleaned. Cleared strip roads are reco mended to provide access. Crop trees in sapling stan should be given about 50 square feet of growing spa per tree to maintain good diameter growth.

Figure 2. — *Clearing strip roads in young stands w facilitate precommercial thinning and provide acce for future cultural operations throughout the ro tion.*

hinning

One of the most important ways stand composition nd development can be controlled is by periodic ommercial thinnings (fig. 3). Stands should be thinned efore they exceed the recommended upper limit of tocking for managed stands (fig. 7, Appendix). A niform distribution of the best quality trees with at ast the minimum recommended stocking for the verage stand diameter should be left, but not over half - and preferably less – of the basal area should be emoved in any one thinning. Stands managed near the inimum recommended stocking will have the most apid diameter growth but the opportunity for selecting rop trees will be more limited because of the fewer ees per acre. As a more general guide, pole stands (5 to inches average diameter) should be considered for hinning when the basal area is 140 square feet or more er acre and they should be thinned to leave about 90 quare feet.

igure 3. – *Periodic thinning of red pine stands can provide useful products and control the growth and development of the final crop trees.*

If a system of access trails for management of the and has not already been developed during precom-ercial thinning, it should be done during the first ommercial thinning. Removal of complete rows in lantations may serve as strip roads but more often than ot strips should cross some rows to provide the most seful access into and out of the stand from the landing working area. A convenient spacing for access strips is to 60 feet which will usually leave a good supply of ees between strips from which to select the crop trees.

Thinnings between access strips should generally be from below to remove the smaller, slower growing intermediate and codominant trees and favor the larger crop trees, but high risk, poor quality, or damaged trees should also be removed. In some dense stands where only the largest trees are merchantable, a commercial thinning would require thinning from above. This is preferable to delaying the first thinning in very dense stands because growth loss from crowding may be even greater. Row thinning is also an alternative that may be considered for the first thinning but all other thinnings should be from below.

Sawtimber trees should be thinned periodically to maintain uniform growth rates on the crop trees. Small sawtimber stands (9 to 15 inches average diameter) grow well at densities around 120 square feet of basal area per acre. Larger sawtimber stands also grow well at these densities but the fewer, larger trees will be using less of the growing space because the crown area of large forest grown trees doesn't increase at the same rate as their basal area. Sawtimber stands averaging 15 inches d.b.h. or more can be managed at densities of 150 or even 180 square feet of basal area per acre (150 or fewer trees) without serious crowding.

In mixed stands red pine crop trees should be favored in each thinning but other species should be left where needed to maintain uniform spacing and avoid large openings.

Pruning

Managed red pine stands that are thinned regularly to provide adequate growing space for the crop trees, especially those managed near the minimum recommended stocking, will need artificial pruning to produce high quality, strong, clear wood. Crop trees should be pruned when they are pole size (5 to 9 inches average diameter) (fig. 4). Branches should be cut off flush with the bole to facilitate rapid healing of wounds. Wounds up to 1 inch will heal over in 5 years or less on healthy trees. Prune live branches no higher than half of the tree's total height. Mechanical pruners are more efficient than hand pruning above 12 feet and will usually be necessary to prune higher than 17 feet.

Regulating the Forest

Forest regulation involves long range planning to assure a continuous systematic development of forest stands and a more uniform flow of useful products. Some important aspects of forest regulation are harvesting

Figure 4. – *The production of high quality, strong, clear wood can be increased by pruning the final crop trees in red pine pole stands.*

methods, rotation ages, maintaining old growth stands, and conversion opportunities.

Harvesting Methods

Silvicultural systems are named after the method of harvesting the final crop trees and preparing the site for establishing a new forest stand. Even-aged silvicultural systems that have been used for managing red pine are clearcutting, seed tree, and shelterwood. Clearcutting is recommended where mature trees are not needed on the area. The seed tree system which has not proved successful because seed crops are infrequent is not recommended. Shelterwood systems also have the same disadvantage but they are recommended where mature trees are needed on the area to bridge the gap from a fully stocked stand of mature trees to a fully stocked stand of seedlings established by planting. If the shelterwood trees are left in narrow strips they can be removed later without damaging the sapling stand. Even-aged systems need a series of different age stands to provide a periodic flow of products and uses. In developing this range of age classes it may be desirable to harvest some stands at younger ages and others at older ages as discussed under "Rotation Ages".

Uneven-aged silvicultural systems include selection c group selection cuttings. Although red pine is not as we suited to these systems as it is to the even-aged system careful cutting of mature trees and frequent release o seedling, sapling, and pole trees makes it possible t grow several age classes in small groups where continu ous high forest cover is needed or desired. These system may also be appropriate for a more even flow o products and uses from small areas where it is no possible to have enough different age classes of even aged stands.

Rotation Ages

Red pine is a long-lived tree providing the opportunit to grow stands to about 200 years where needed. Bu with periodic thinnings to the minimum recommende basal area densities, the average tree can reach 20 inche in diameter on the best sites in about 60 years Culmination of mean annual board foot growth in stand periodically thinned to the *same* basal area densit depends on the basal area left after the thinnings (tabl 11, Appendix). Growth culminates earlier in stand periodically thinned to basal area levels below th minimum recommended stocking but total stand growt is also lower. Growing stands at higher densities (abou 120 square feet of basal area) on longer rotations (120 to 140 years) will produce a higher annual growth an yield. The rotation age for sawtimber should be se within this biological range of 60 to 200 years on th basis of other needs and considerations. One need migh be to adjust the distribution of age classes for regulatin the forest. In areas that lack old growth stands, som young stands could be managed at low densities an short rotations to supply needed sawtimber for the shor run. Where old growth stands are available, the rotation of some stands may be extended to allow time fo younger stands to reach sawtimber size.

Maintaining Old Growth Stands

Extending rotations to allow young stands of pole timber to reach sawtimber size should be limited t healthy, vigorous stands that have at least the minimun recommended stocking (fig. 7, Appendix). Higher stock ing is desirable to maintain good growth in old stand because the height growth is very low. Basal area growt also decreases with age but is still over 2 feet per acr per year for the higher density stands on the better site (table 4, Appendix). Old growth stands should have onl light salvage cuts to keep them healthy and vigorous an to prevent the development of dense shrub understories Old growth stands should be harvested by 200 years o age and new stands established in the same manner a recommended for mature stands.

Conversion Opportunities

In building the red pine resource for the future, new stands should be established as rapidly as possible so the forest will be fairly well regulated as the stands mature. Red pine should be restored on former pine land that is now poorly stocked or stocked with less desirable species. Conversion of nonstocked brush areas and aspen or oak types to red pine on a regular basis will establish a fully regulated red pine forest in one rotation. Priorities for conversion will vary somewhat with the forest owner's objective and capabilities, but general recommendations are nonstocked areas, poorly stocked mature stands, other mature stands, poorly stocked immature stands, and other immature stands, in that order. Stands with a lot of high risk or low quality trees should be converted before stands with fewer such trees. Conversion of stands that will be merchantable in 20 years or less should be delayed so the harvesting operation can help clear the site and aid the job of site preparation.

Controlling Stand Establishment

Site Evaluation

Before establishing a red pine stand, some estimate of its potential growth on the area should be obtained. If there are red pine trees over 30 years old on the area that have never been suppressed, the best estimate of site index is from site index equations or curves based on the total height and total age of the dominant and codominant trees (fig. 8, Appendix).

Red pine trees starting at about 15 years of age can also provide good estimates of site index based on the following tabulation:

Length of 5 internodes above 8 feet	Site index[3]
(Feet)	(Feet)
4	38
5	46
6	52
7	56
8	61
9	65
10	68
11	72
12	76

[3]*Based on a revised equation adapted from Alban (1972); site index = $36.9 + 3.356(x) - 192.474\ (x)^{-2}$; where x equals length of 5 internodes above 8 feet.*

Other growth intercept methods based on 1 to 5 years' growth above breast height (4.5 feet) have been used but estimates of site index are less reliable. Their advantage is that they can be used on red pine trees with only a few years' growth above breast height. The following simplified tabulation shows approximate site index based on average annual height growth for one to five years above breast height:

Average annual height growth above breast height	Approximate site index[4]
(Inches)	(Feet)
10	45
13	55
17	65
24	75

Considerable variation in annual growth can be expected from year to year so whenever possible the full 5 years' growth should be measured to obtain the average annual growth for estimating site index. Site index will be slightly underestimated when based on 1 year's average and slightly overestimated when based on the average of 5 years' growth using this table.

Site index for red pine can also be estimated from the site index of other trees growing on the area if they have not been suppressed. Jack pine, white pine, white spruce, or aspen site index can be used to estimate red pine site index as in the following generalized tabulation:

Red pine[5]	Jack pine	White pine	White spruce	Aspen
		(Feet)		
45	50	45	35	40
55	60	55	50	60
65	70	65	65	80
75	80	75	80	100

If no suitable trees are available for site index measures, soil properties can be used to estimate red pine site index on sand to sandy loam soils (table 1, Appendix). The factors needed are the depth of the A and B horizons, the percent gravel in the surface 10 inches, and the presence or absence of finer textured soil bands or layers totaling at least 6 inches within 8 feet of the surface. These factors will permit estimates of site

[4]*Adapted from Day* et al. *(1960), and Schallau and Miller (1966).*

[5]*Adapted from Carmean and Vasilevsky (1971), and Alban (1976).*

index for red pine on sand to sandy loam soils where red pine is recommended. Other species such as white spruce, aspen, or northern hardwoods are usually recommended on finer textured soils.

In evaluating sites for red pine it is important to remember that site index predicts the height of dominant trees in a stand at 50 years of age and must be related to yields before comparing productivity between species. For example, side-by-side stands of 40-year-old red pine and jack pine growing on a fine sandy loam had site indices of 68 and 70 feet, respectively, but the red pine stand had 55 percent more total cubic foot volume than the jack pine stand. The red pine stand had grown to 225 square feet of basal area per acre compared to only 152 square feet in the jack pine stand.

Another important part of site evaluation is determining the need for site preparation to establish a new stand. Generally the higher the site quality the greater the need to control competing sod, shrubs, and trees to favor the establishment of red pine.

Site Preparation

A good job of site preparation should eliminate competition for light, water, and nutrients without causing any serious risk of soil loss (fig. 5). Minimum site preparation of only seeding or planting spots offers the most site protection but may require frequent follow-up release of the pine seedlings. Complete site preparation will reduce the need for follow-up release but may expose the site to erosion, severe drying, or be an eyesore. On some areas full-tree skidding to remove slash may be all the site preparation needed but on most areas shrubs should be controlled and mineral soil exposed.

Figure 5. — *A thorough job of site preparation favors the establishment of red pine seedlings.*

Mechanical equipment, herbicides, prescribed burning, or a combination may be used for site preparation. The use of mechanical equipment depends on the job that needs to be done and the availability of equipment. Some of the common kinds of equipment used to prepare sites for red pine establishment are bulldozers, shearing blades, heavy duty discs, rototillers, plows, root rakes, rock rakes, drum choppers, and many kinds of homemade scarifiers to knock down the shrubs and loosen the soil. Under some conditions the loosened soil may be difficult to properly pack around planted seedlings resulting in a high rate of mortality.

The most commonly used herbicides to control shrubs and hardwoods are the same ones used for seedling release – 2,4-D and 2,4,5-T.[2] Foliar spraying should be done as soon as the shoot growth is complete, when it is the most effective, about mid-July in northern Minnesota and a little earlier further south. Grass and herbaceous plants can be controlled with Amitrol[2] or Dalapon,[2] and Simazine[2] can be used to prevent regrowth during the year. Follow-up treatments may be needed the next year especially on areas of heavy sod.

Prescribed burning is usually most effective for site preparation soon after harvesting when slash accumulations provide plenty of fuel for a hot fire. Conifer slash can be burned almost immediately but hardwood slash needs to cure for several weeks to get good results. In mature red pine stands one or more summer fires can be prescribed to eliminate the shrubs and reduce the depth of organic material on the seedbeds prior to harvesting (fig. 6). Burning plans should be approved and permits obtained where required.

Seeding and Planting

Natural seeding during good seed years can successfully establish seedlings on seedbeds such as those prepared by summer prescribed burning under a mature stand of red pine. Scarifying the soil may also be successful if shrubs are not present. Red pine seed years, however, are so infrequent that seed should be collected during good seed years for direct seeding or growing seedlings to plant.

igure 6. – *Controlled summer fires can eliminate most of the woody understory in red pine stands before harvesting and help prepare favorable conditions for establishing red pine seedlings at the end of the rotation.*

Direct seeding has not enjoyed widespread success, but northeast Minnesota it has been successful on well epared sites if frequent rain storms occur during the st few months after germination. Seed should be ated with bird and rodent repellants and sown at the te of 15,000 viable seeds per acre (about 5 ounces) rly in the spring to take advantage of snowmelt waters r germination. Somewhat better results have been perienced by covering red pine seed with 1/4 inch of il but it may be more expedient to broadcast more ed on the surface than to use less seed and cover it. It easier to cover the seed when sowing 5 to 10 seeds in epared spots. Even though direct seeding can be ccessful it generally has not been because of inade-iate site preparation, inadequate precipitation, or loss seeds to birds or rodents.

The most reliable method of establishing a red pine and is to plant nursery-grown trees. Planting of bare ot stock should be done in the spring setting the trees least as deep as they grew in the nursery. On drier es planting trees up to 2 inches deeper may be neficial, but planting trees too deep increases the risk injury by root collar weevils. The more difficult sites ould be planted with bare root transplant stock or ge vigorous seedlings. Container-grown trees show omise for planting throughout the growing season.

The spacing of planted trees determines how the trees will develop during their early years and how soon the stand will close in and affect the ground cover. Spacings closer than 5 feet will not provide the minimum growing space recommended for seedlings, and spacings greater than 10 feet will not provide the minimum number of seedlings recommended per acre. The time to reach pole size (5 inches diameter) will vary from 15 to 30 or more years depending mostly on the spacing or number of trees per acre established and to a lesser extent on the site quality (table 2, Appendix). The closer spacings will require cleaning (precommercial thinning) during the sapling stage (2 to 5 inches average diameter) to provide the recommended 50 square feet of growing space for each crop tree, and the wider spacings may need an extra release or two to control grass, shrub, and hardwood competition.

Planting recommendations depend on many things including the forest owner's objective, planting chance, and management intensity. Planting 400 trees per acre (a little more than 10- by 10-foot spacing) will be the least costly, crop trees will have rapid diameter growth, commercial thinnings can be made by the time trees need more growing space, and crown closure will not shade out ground vegetation for about 20 years. Planting 1,600 trees per acre (a little more than 5- by 5-foot spacing) will allow greater flexibility in selecting crop trees and controlling early stand development, crop trees will have less taper and smaller branches, and the stand will have more total volume.

Trees should be planted at wide spacings up to 10 by 10 feet if: all or most of the planted trees have a good chance of surviving, precommercial thinnings are not feasible (or not planned), and favoring ground vegetation is a management objective. On the other hand trees should be planted at close spacings down to 5 by 5 feet if: tree quality such as taper and branch size is important, early crown closure to suppress competition is desired, precommercial and early thinnings are planned to control stand development, and frequent thinnings are wanted throughout the rotation. Most plantations will be established at spacings between these two extremes. Commonly used spacings are 6 by 8 and 6 by 10 feet. Machine planting costs can be reduced by using wider rows and closer spacing of trees in the row but plans for access and future management operations should also be considered at the time of stand establishment.

OTHER RESOURCE CONDITIONS

Recreation

Red pine stands are popular places for hiking, camping, and other recreational activities especially when the trees are large and located near a lake or stream. Management considerations for recreation should include long rotations to maintain a higher proportion of the forest in large, old-growth trees. For example, a fully regulated red pine forest with rotation ages of 150 years would have two-thirds of the area in stands over 50 years old compared to only half the area if 100-year rotations were used. Young stands should be managed near the minimum recommended stocking to obtain large trees as soon as possible but older stands should be managed nearer the upper limits to reduce development of unwanted understory plants and increase the opportunity to extend the rotation. New stands should be established regularly to provide continuous stands of large old growth trees for the future. Understory development in large old-growth stands may be controlled to enhance the park-like appearance of recreation areas.

Operations in stands with high recreational value should be done during periods of minimal use. Recreational users should be informed about management operations and encouraged to rotate their use as the mature stands complete their cycle. In some special areas it may be necessary to use uneven-aged management to maintain a continuous stand of mature trees. On these areas considerable work will be necessary to bring through the required number of seedling, sapling, and poletimber trees to replace the mature trees as they are periodically removed.

Water

Red pine forests usually cover only a part of a watershed so management activities should be coordinated with those on other areas in the watershed to maintain an even flow of high quality water. Stands managed near the minimum recommended stocking will have higher water yield. Care is needed in harvesting trees near streams and lakes to prevent soil and debris from getting into the water. Some stream crossings may require culverts. Landings should be carefully planned and trails should be kept back away from shorelines and streambanks to prevent soil from eroding into the water. Trees should be felled away from the water and winched to the nearest skid trail. Intermittent stream channels should not be used for skidding. Timber harvesting when soils are frozen will reduce erosion hazards on some areas.

Wildlife

Red pine stands are generally considered poor habitat for game birds and animals but they provide cover and nesting sites for many species of wildlife. Large old-growth trees are used by the American bald eagle as well as many songbirds.

Although red pine stands offer good shelter for wildlife, many of the favored food plants are not found in the understory. Managing stands near the minimum recommended stocking will favor a greater variety of understory plants. Prescribed burning may also be effective in developing a more favorable understory for wildlife food. Carefully planned landings can serve as wildlife openings providing some of the food plants needed. Landings should be at least 1/2 acre for an effective wildlife opening.

APPENDIX

Stocking Chart

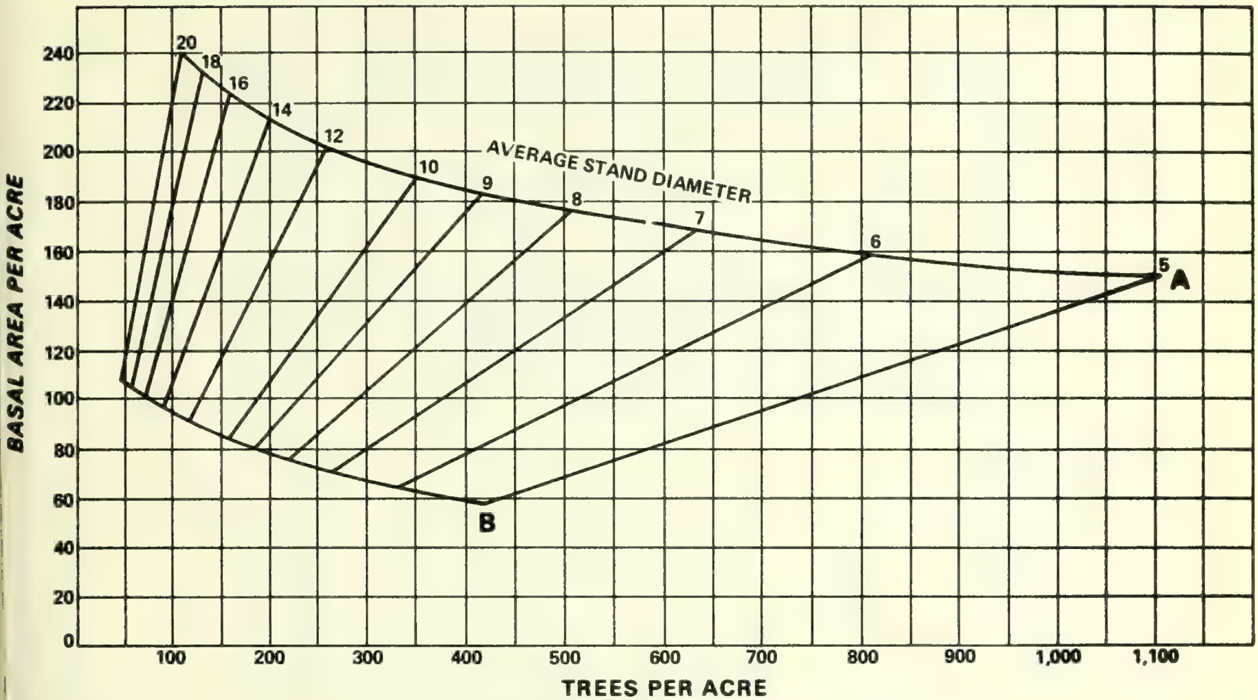

Figure 7. – *Stocking chart for managed red pine stands.*

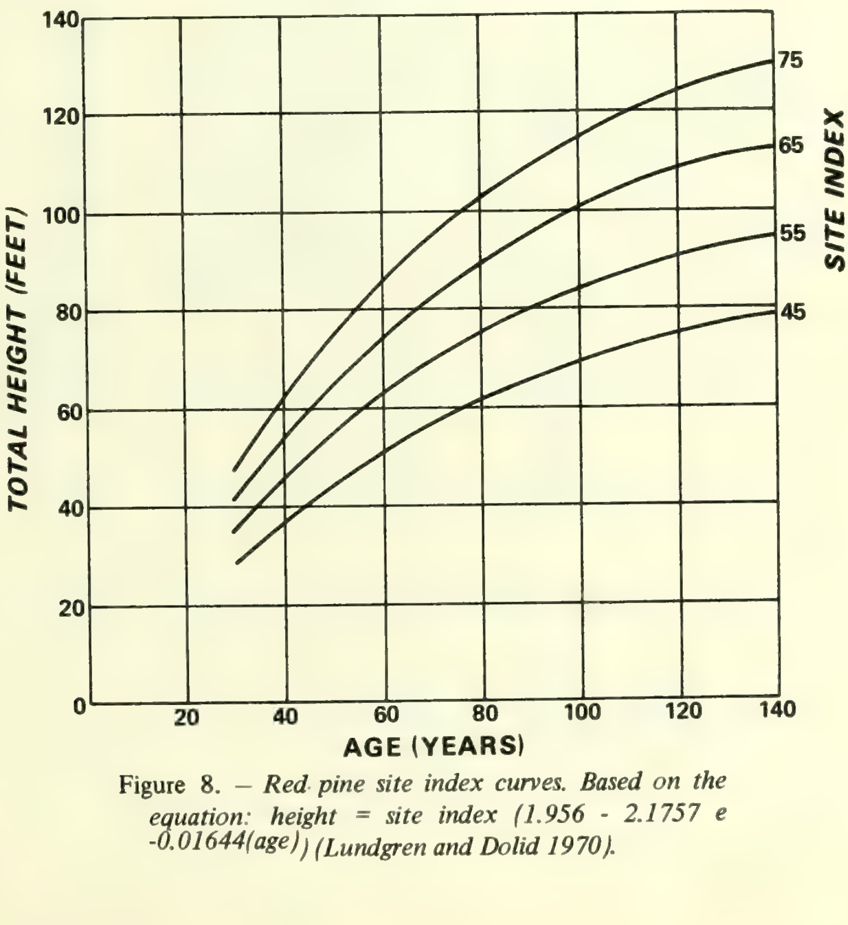

Figure 8. – *Red pine site index curves. Based on the equation: height = site index (1.956 - 2.1757 e $^{-0.01644(age)}$) (Lundgren and Dolid 1970).*

Table 1. — *Estimated site index for red pine plantations in the Lake States on well drained sand to sandy loam soils*[1]

Gravel or rocks in top 10 inches	Depth of A plus B horizons (inches) 5	10	20	30	40	50
Percent by weight	*Site Index (Feet)*					
0	55	57	60	63	67	70
10	52	54	57	60	63	67
20	49	51	54	57	60	63
30	46	48	51	54	57	60
40	43	45	48	51	54	57
50	40	41	44	48	51	54

[1]Add 5 feet to site index on soils with bands or layers of finer textured material within 8 feet of the surface that improve water relations. Subtract 5 feet from site index for natural stands. (Adapted for the Lake States from Alban (1976).)

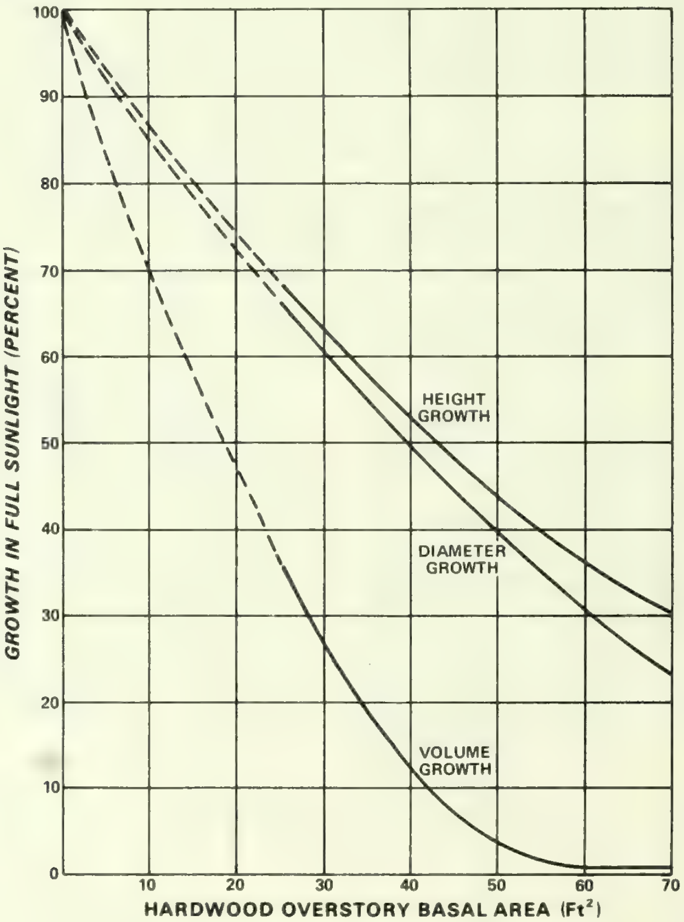

Figure 9. — *Influence of hardwood overstory basal area on the growth of planted red pine. Based on red pine release studies in nine plantations ranging from 2 to 40 years old on medium to good sites in Lower Michigan. Cooley, J. 1975. Unpublished report on file at North Central Forest Experiment Station, Grand Rapids, Minnesota.*

Growth and Yield Tables

Table 2. – *Average d.b.h. of young red pine stands*[1]

Total age	Total height	Number of trees per acre: 400	800	1200	1600	2000
Years	*Feet*	- - - -	- - -	*Inches*	- - -	- - - -
SITE INDEX 75						
15	21	5.2	4.5	3.9	3.5	3.2
20	30	6.5	5.6	4.9	4.4	4.0
25	38	7.4	6.4	5.6	5.0	4.5
30	46	8.2	7.0	6.1	5.5	5.0
SITE INDEX 65						
15	19	4.7	4.0	3.5	3.2	2.9
20	26	6.0	5.1	4.5	4.0	3.6
25	33	6.9	5.9	5.2	4.6	4.2
30	40	7.5	6.5	5.7	5.1	4.6
SITE INDEX 55						
15	16	4.2	3.6	3.2	2.8	2.6
20	22	5.4	4.6	4.0	3.6	3.3
25	28	6.2	5.4	4.7	4.2	3.8
30	34	6.9	5.9	5.2	4.6	4.2
SITE INDEX 45						
15	13	3.6	3.1	2.7	2.4	2.2
20	18	4.8	4.1	3.6	3.2	2.9
25	23	5.6	4.8	4.2	3.7	3.4
30	28	6.2	5.3	4.8	4.1	3.8

[1]Computed from table 3 as diameter of tree of average basal area.

Table 3. – *Estimated basal area*[1] *of young red pine stands*

Total age	Total height	Number of trees per acre: 400	800	1200	1600	2000
Years	*Feet*	- - - -	- - -	*Square Feet*	- - -	- - - -
SITE INDEX 75						
15	21	59	87	101	107	110
20	30	93	136	157	167[2]	171
25	38	121	178	205	218	224
30	46	145	214	246	261	268
SITE INDEX 65						
15	19	48	71	82	87	89
20	26	78	114	131	140	143
25	33	103	151	174	185	190
30	40	124	183	210	223	229
SITE INDEX 55						
15	16	38	56	65	69	71
20	22	63	93	107	114	117
25	28	85	125	144	153	157
30	34	103	152	175	186	191
SITE INDEX 45						
15	13	29	43	49	52	54
20	18	50	73	84	90	92
25	23	68	100	115	122	125
30	28	83	122	141	150	154

[1]Based on the equation $B = 6.565302(S)(1-e^{-.0401718(BHA)})^{1.1677}(1-e^{-.0018854N})$ where B = basal area, S = site index, BHA = breast height age, and N = number of trees established. Breast height age = total age - 10.5 +0.05(site). Equations were developed by A. L. Lundgren from data collected by R. F. Wambach (1967).

[2]Thinnings are recommended for the stands shown enclosed.

Table 4. — *Current annual basal area growth per acre*[1] *for even-aged red pine stands by site, age, and stand density*

SITE INDEX 75

Total age	Total height	Stand density - basal area per acre 30	60	90	120	150	180
Years	*Feet*	- - - - - - - - *Square Feet*	- - - - - -				
20	30	6.2	6.9	7.4	7.6	7.6	7.2
40	61	4.9	5.7	6.2	6.4	6.3	5.9
60	86	3.8	4.6	5.1	5.3	5.2	4.8
80	103	2.9	3.7	4.2	4.4	4.3	3.9
100	115	2.2	3.0	3.5	3.7	3.6	3.2
120	124	1.6	2.4	2.9	3.1	3.0	2.7
140	130	1.3	2.1	2.6	2.8	2.7	2.3
160	134	1.1	1.9	2.4	2.6	2.5	2.1
SITE INDEX 65							
20	26	5.5	6.3	6.8	7.0	6.9	6.5
40	53	4.2	5.0	5.5	5.7	5.6	5.3
60	74	3.2	4.0	4.4	4.6	4.6	4.2
80	89	2.3	3.1	3.5	3.8	3.7	3.3
100	100	1.5	2.3	2.8	3.0	2.9	2.6
120	107	1.0	1.8	2.3	2.5	2.4	2.0
140	112	.6	1.4	1.9	2.1	2.0	1.7
160	116	.5	1.3	1.8	2.0	1.9	1.5
SITE INDEX 55							
20	22	4.9	5.7	6.2	6.4	6.3	5.9
40	45	3.6	4.4	4.9	5.1	5.0	4.6
60	63	2.5	3.3	3.8	4.0	3.9	3.5
80	76	1.6	2.4	2.9	3.1	3.0	2.6
100	85	.9	1.7	2.2	2.4	2.3	1.9
120	91	.4	1.1	1.6	1.9	1.8	1.4
140	95	--	.8	1.3	1.5	1.4	1.0
160	98	--	.6	1.1	1.3	1.2	.8
SITE INDEX 45							
20	18	4.2	5.0	5.5	5.7	5.6	5.2
40	37	3.0	3.7	4.2	4.5	4.4	4.0
60	51	1.9	2.7	3.2	3.4	3.3	2.9
80	62	1.0	1.8	2.3	2.5	2.4	2.0
100	69	.2	1.0	1.5	1.7	1.6	1.3
120	74	--	.5	1.0	1.2	1.1	.7
140	78	--	.1	.6	.8	.8	.4
160	80	--	--	.5	.7	.6	.2

[1] BA growth = 1.6889 + .041066 (BA) − .0016303 $(BA)^2$ − .076958 (Age) + .00022741 $(Age)^2$ + .06441 (Site Index) (Buckman 1962).

Table 5. – *Volume*[1] *in cubic feet per acre for even-aged red pine stands by site, age, and stand density*

Total age	Total height	Stand density - basal area per acre: 30	60	90	120	150	180
Years	*Feet*	*Cunits (100 cubic feet) per acre*[2]					
SITE INDEX 75							
20	30	3.7	7.3	11.0	14.7	18.4	22.0
40	61	7.5	14.9	22.4	29.9	37.3	44.8
60	86	10.5	21.0	31.6	42.1	52.6	63.2
80	103	12.6	25.2	37.8	50.4	63.0	75.6
100	115	14.1	28.2	42.2	56.3	70.4	84.5
120	124	15.2	30.4	45.4	60.7	75.9	91.1
140	130	15.9	31.8	47.7	63.6	79.6	95.5
160	134	16.4	32.8	49.2	65.6	82.0	98.4
SITE INDEX 65							
20	26	3.2	6.4	9.5	12.7	15.9	19.1
40	53	6.5	13.0	19.5	25.9	32.4	38.9
60	74	9.0	18.1	27.2	36.2	45.3	54.3
80	89	10.9	21.8	32.7	43.6	54.5	65.4
100	100	12.2	24.5	36.7	49.0	61.2	73.4
120	107	13.1	26.2	39.3	52.4	65.5	78.6
140	112	13.7	27.4	41.1	54.8	68.5	82.2
160	116	14.2	28.4	42.6	56.8	71.0	85.2
SITE INDEX 55							
20	22	2.7	5.4	8.1	10.8	13.5	16.2
40	45	5.5	11.0	16.5	22.0	27.5	33.0
60	63	7.7	15.4	23.1	30.8	38.6	46.3
80	76	9.3	18.6	27.9	37.2	46.5	55.8
100	85	10.4	20.8	31.2	41.6	52.0	62.4
120	91	11.1	22.3	33.4	44.6	55.7	66.8
140	95	11.6	23.2	34.9	46.5	58.1	69.8
160	98	12.0	24.0	36.0	48.0	60.0	72.0
SITE INDEX 45							
20	18	2.2	4.4	6.6	8.8	11.0	13.2
40	37	4.5	9.1	13.6	18.1	22.6	27.2
60	51	6.2	12.5	18.7	25.0	31.2	37.4
80	62	7.6	15.2	22.8	30.4	37.9	45.5
100	69	8.4	16.9	25.3	33.8	42.2	50.7
120	74	9.1	18.1	27.2	36.2	45.3	54.3
140	78	9.5	19.1	28.6	38.2	47.7	57.3
160	80	9.8	19.6	29.4	39.2	49.0	58.8

[1]Cubic feet = 0.4085 (Basal area x Height) (Buckman 1962).

[2]Total main stem volume in cunits from 6-inch stump to tip of tree. Estimated cunits to a 4-inch top d.i.b. can be obtained by subtracting

$$1.067\left(\frac{\text{Basal area per acre in sq. ft.}}{\text{ave. tree diameter in inches squared}}\right)$$

Table 6. – *Current annual cubic foot growth*[1] *per acre for even-aged red pine stands by site, age, and stand density*

Total age	Total height	Stand density - basal area per acre: 30	60	90	120	150	180
Years	*Feet*	- - - - - - *Cubic feet* - - - - - - -					
SITE INDEX 75							
20	30	101	131	158	182	203	218
40	61	142	180	210	232	246	253
60	86	147	188	218	237	246	244
80	103	131	174	204	221	225	217
100	115	110	154	184	199	200	188
120	124	85	129	158	172	171	159
140	130	72	117	146	159	156	137
160	134	63	109	139	152	149	130
SITE INDEX 65							
20	26	80	108	132	152	169	183
40	53	108	140	166	185	198	206
60	74	109	144	168	185	196	195
80	89	92	128	150	168	172	165
100	100	66	104	130	143	143	136
120	107	48	86	112	124	124	110
140	112	30	69	94	106	104	93
160	116	25	64	89	100	96	78
SITE INDEX 55							
20	22	61	83	103	119	133	144
40	45	80	107	129	145	155	160
60	63	75	106	128	143	151	150
80	76	56	87	109	121	124	118
100	85	36	69	91	103	105	96
120	91	19	48	71	86	86	74
140	95	--	36	58	68	67	54
160	98	--	26	48	57	54	39
SITE INDEX 45							
20	18	45	63	79	93	105	114
40	37	56	77	94	109	117	121
60	51	47	72	90	101	106	105
80	62	30	56	73	83	86	80
100	69	9	36	53	63	64	59
120	74	--	20	38	46	46	36
140	78	--	6	23	30	32	20
160	80	--	--	20	28	26	14

[1]Cubic feet growth = 0.4085 (basal area growth x height + height growth x basal area + basal area growth x height growth) (Buckman 1962).

Table 7. – *Volume in cords per acre*[1] *for even-aged red pine stands by site, age, and stand density*

Total age	Total height	Stand density basal area per acre[2] 30	60	90	120	150	180
Years	*Feet*	Cords					
SITE INDEX 75							
40	61	7.2	14.5	21.7	29.0	36.2	43.5
60	86	10.2	20.4	30.6	40.8	51.0	61.3
80	103	12.2	24.5	36.7	48.9	61.2	73.4
100	115	13.6	27.3	41.0	54.6	68.3	81.9
120	124	14.7	29.4	44.2	58.9	73.6	88.3
140	130	15.4	30.9	46.3	61.7	77.2	92.6
160	134	15.9	31.8	47.7	63.6	79.6	95.5
SITE INDEX 65							
40	53	6.3	12.6	18.9	25.2	31.5	37.8
60	74	8.8	17.6	26.4	35.1	43.9	52.7
80	89	10.6	21.1	31.7	42.3	52.8	63.4
100	100	11.9	23.7	35.6	47.5	59.4	71.2
120	107	12.7	25.4	38.1	50.8	63.5	76.2
140	112	13.3	26.6	39.9	53.2	66.5	79.8
160	116	13.8	27.5	41.3	55.1	68.9	82.6
SITE INDEX 55							
40	45	5.3	10.7	16.0	21.4	26.7	32.0
60	63	7.5	15.0	22.4	29.9	37.4	44.9
80	76	9.0	18.0	27.1	36.1	45.1	54.1
100	85	10.1	20.2	30.3	40.4	50.5	60.5
120	91	10.8	21.6	32.4	43.2	54.0	64.8
140	95	11.3	22.6	33.8	45.1	56.4	67.7
160	98	11.6	23.3	34.9	46.5	58.2	69.8
SITE INDEX 45							
40	37	4.4	8.8	13.2	17.6	22.0	26.4
60	51	6.1	12.1	18.2	24.2	30.3	36.3
80	62	7.4	14.7	22.1	29.4	36.8	44.2
100	69	8.2	16.4	24.6	32.8	41.0	49.2
120	74	8.8	17.6	26.4	35.1	43.9	52.7
140	78	9.3	18.5	27.8	37.0	46.3	55.6
160	80	9.5	19.0	28.5	38.0	47.5	57.0

[1]Cords = 0.003958 (Basal area x Height). Rough cords for trees 3.6 inches DBH and larger to a 3-inch top d.i.b. (Buckman 1962).

Table 8. – *Current annual cordwood growth per acre*[1] *for even-aged red pine stands by site, age, and stand density*

Total age	Total height	Stand density - basal area per acre[2] 30	60	90	120	150	180
Years	*Feet*	Cords					
SITE INDEX 75							
40	61	1.3	1.7	2.0	2.2	2.4	2.4
60	86	1.4	1.8	2.1	2.3	2.4	2.4
80	103	1.3	1.7	2.0	2.1	2.2	2.1
100	115	1.1	1.5	1.8	1.9	1.9	1.8
120	124	.8	1.2	1.5	1.7	1.6	1.5
140	130	.7	1.1	1.4	1.5	1.5	1.3
160	134	.6	1.0	1.3	1.5	1.4	1.3
SITE INDEX 65							
40	53	1.0	1.4	1.6	1.8	1.9	2.0
60	74	1.1	1.4	1.6	1.8	1.9	1.9
80	89	.9	1.2	1.5	1.6	1.7	1.6
100	100	.6	1.0	1.3	1.4	1.4	1.3
120	107	.5	.8	1.1	1.2	1.2	1.1
140	112	.3	.7	.9	1.0	1.0	.9
160	116	.2	.6	.9	1.0	.9	.8
SITE INDEX 55							
40	45	.8	1.0	1.2	1.4	1.5	1.5
60	63	.7	1.0	1.2	1.4	1.5	1.5
80	76	.5	.8	1.1	1.2	1.2	1.1
100	85	.4	.7	.9	1.0	1.0	.9
120	91	.2	.5	.7	.8	.8	.7
140	95	--	.3	.6	.7	.6	.5
160	98	--	.3	.5	.6	.5	.4
SITE INDEX 45							
40	37	.5	.7	.9	1.0	1.1	1.2
60	51	.5	.7	.9	1.0	1.0	1.0
80	62	.3	.5	.7	.8	.8	.8
100	69	.1	.3	.5	.6	.6	.6
120	74	--	.2	.4	.4	.4	.3
140	78	--	.1	.2	.3	.3	.2
160	80	--	--	.2	.3	.2	.1

[1]Cordwood growth = .003958 (basal area growth x height + height growth x basal area + basal area growth x height growth) (Buckman 1962).

Table 9. – *Volume in M board feet per acre*[1] *for even-aged red pine stands by site, age, and stand density*

Total age	Total height	Stand density - basal area per acre[2]: 30	60	90	120	150	180
Years	*Feet*	- - - - - - *M Board feet* - - - - - -					
SITE INDEX 75							
60	86	5.4	10.8	16.1	21.5	26.9	32.3
80	103	6.4	12.9	19.3	25.8	32.2	38.6
100	115	7.2	14.4	21.6	28.8	35.9	43.1
120	124	7.8	15.5	23.3	31.0	38.8	46.5
140	130	8.1	16.3	24.4	32.5	40.6	48.8
160	134	8.4	16.8	25.1	33.5	41.9	50.3
SITE INDEX 65							
60	74	4.6	9.2	13.9	18.5	23.1	27.8
80	89	5.6	11.1	16.7	22.3	27.8	33.4
100	100	6.3	12.5	18.8	25.0	31.3	37.5
120	107	6.7	13.4	20.1	26.8	33.4	40.1
140	112	7.0	14.0	21.0	28.0	35.0	42.0
160	116	7.2	14.5	21.8	29.0	36.3	43.5
SITE INDEX 55							
60	63	3.9	7.9	11.8	15.8	19.7	23.6
80	76	4.7	9.5	14.2	19.0	23.8	28.5
100	85	5.3	10.6	15.9	21.3	26.6	31.9
120	91	5.7	11.4	17.1	22.8	28.4	34.1
140	95	5.9	11.9	17.8	23.8	29.7	35.6
160	98	6.1	12.2	18.4	24.5	30.6	36.8
SITE INDEX 45							
60	51	3.2	6.4	9.6	12.8	15.9	19.1
80	62	3.9	7.8	11.6	15.5	19.4	23.3
100	69	4.4	8.6	12.9	17.3	21.6	25.9
120	74	4.6	9.2	13.9	18.5	23.1	27.8
140	78	4.9	9.8	14.6	19.5	24.4	29.3
160	80	5.0	10.0	15.0	20.0	25.0	30.0

[1]Board feet = 2.084 (Basal area x Height). Board-foot volume by Scribner Dec. C. log rule for trees 7.6 inches DBH to a 6-inch top d.i.b. (Buckman 1962).

[2]Must be in trees 7.6 inches DBH and larger.

Table 10. – *Current annual board foot growth per acre*[1] *for even-aged red pine stands by site, age, and stand density*

Total age	Total height	Stand density - basal area per acre[2]: 30	60	90	120	150	180
Years	*Feet*	- - - - - - - - *Board feet* - - - - - - - -					
SITE INDEX 75							
60	86	751	959	1112	1211	1255	1245
80	103	670	887	1039	1126	1148	1105
100	115	560	785	936	1016	1023	958
120	124	433	659	807	878	871	812
140	130	365	595	743	810	795	699
160	134	320	556	709	777	762	662
SITE INDEX 65							
60	74	556	737	856	943	999	993
80	89	467	654	766	860	878	841
100	100	339	531	661	728	732	694
120	107	242	440	571	634	630	560
140	112	153	352	482	541	530	472
160	116	127	327	454	509	491	400
SITE INDEX 55							
60	63	382	539	655	732	769	765
80	76	286	445	556	619	635	602
100	85	185	352	466	527	534	488
120	91	95	247	361	436	436	379
140	95	--	184	295	348	340	273
160	98	--	135	244	291	276	201
SITE INDEX 45							
60	51	242	365	457	516	542	537
80	62	155	284	374	425	437	410
100	69	48	182	273	320	325	300
120	74	--	102	192	236	233	183
140	78	--	29	116	155	161	103
160	80	--	--	102	142	131	71

[1]Board foot growth = 2.084 (basal area growth x height + height growth x basal area + basal area growth x height growth) (Buckman 1962).

[2]Must be in trees 7.6 inches DBH and larger.

Table 11. – *Rotation ages for maximum mean annual board foot growth*[1] *in red pine periodically thinned to a given stand density by site index*

Planted trees/A	Basal area density after periodic thinning: 30	60	90	120	150	180
Number						
SITE INDEX 75						
	Rotation age - years					
400	63	93	103	113	118	103
800	83	103	103	113	143	123
1200	83	103	113	123	--[2]	--
1600	103	113	113	143	--	--
	Board feet per acre per year					
400	331	614	831	980	1013	841
800	302	561	775	894	867	654
1200	297	542	713	813	--	--
1600	286	507	682	757	--	--
SITE INDEX 65						
	Rotation age - years					
400	93	83	103	103	123	98
800	83	103	103	133	148	118
1200	103	103	113	143	--	--
1600	103	113	118	143	--	--
	Board feet per acre per year					
400	247	471	654	774	732	618
800	237	447	605	676	583	415
1200	231	422	559	611	--	--
1600	222	402	524	558	--	--
SITE INDEX 55						
	Rotation age - years					
400	93	93	103	118	113	78
800	93	103	123	143	138	143
1200	103	103	133	--	--	--
1600	123	133	143	--	--	--
	Board feet per acre per year					
400	189	367	496	555	492	394
800	184	336	451	448	340	161
1200	172	322	411	--	--	--
1600	151	275	346	--	--	--
SITE INDEX 45						
	Rotation age - years					
400	98	108	123	118	88	88
800	103	123	128	138	--	--
1200	103	118	143	--	--	--
1600	103	133	--	--	--	--
	Board feet per acre per year					
400	124	245	336	329	263	263
800	113	217	259	226	--	--
1200	104	187	211	--	--	--
1600	97	156	--	--	--	--

Source: Unpublished red pine yield tables for managed plantations and natural stands in the Lake States. Computer program developed by A. L. Lundgren (1971), from growth and yield studies at the Northern Conifers Laboratory by R. E. Buckman and R. F. Wambach.

[1]International 1/4-inch board foot volumes in trees 9 inches d.b.h. and larger to a 6-inch top d.i.b.

[2]Mean annual growth did not culminate prior to 153 years of age in these high density stands.

Metric Conversion Factors

To convert	*to*	*Multiply by*
Acres	Hectares	0.405
Board feet[1]	Cubic meters	0.005
Board feet/acre[1]	Cubic meters/hectare	0.012
Chains	Meters	20.117
Cords[1]	Cubic meters	2.605
Cords/acre[1]	Cubic meters/hectare	6.437
Cubic feet	Cubic meters	0.028
Cubic feet/acre	Cubic meters/hectare	0.070
Degrees Fahrenheit	Degrees Celsius	[2]
Feet	Meters	0.305
Gallons	Liters	3.785
Gallons/acre	Liters/hectare	9.353
Inches	Centimeters	2.540
Miles	Kilometers	1.609
Miles/hour	Meters/second	0.447
Number/acre	Number/hectare	2.471
Ounces	Grams	28.350
Ounces/acre	Grams/hectare	70.053
Pounds	Kilograms	0.454
Pounds/acre	Kilograms/hectare	1.121
Pounds/gallon	Kilograms/liter	0.120
Square feet	Square meters	0.093
Square feet/acre	Square meters/hectare	0.230
Tons	Metric tons	0.907
Tons/acre	Metric tons/hectare	2.242

[1]The conversion of board feet and cords to cubic meters can only be approximate; the factors are based on an assumed 5.663 board feet (log scale) per cubic foot and a cord with 92 cubic feet of solid material.

[2]To convert °F to °C, use the formula 5/9 (°F-32) or $\frac{°F-32}{1.8}$.

Common and Scientific Names of Plants and Animals

Common name	*Scientific name*
Plants	
Aspen, bigtooth	*Populus grandidentata*
quaking	*Populus tremuloides*
Birch, paper	*Betula papyrifera*
Blackberries	*Rubus occidentalis*
Blueberries	*Vaccinium spp.*
Fir, balsam	*Abies balsamea*
Hazel	*Corylus spp.*
Juneberries	*Amelanchier spp.*
Maple, red	*Acer rubrum*
sugar	*Acer saccharum*
Oak, bur (scrub)	*Quercus macrocarpa*
no. pin	*Quercus ellipsoidalis*
no. red	*Quercus rubra*
Pine, jack	*Pinus banksiana*
red	*Pinus resinosa*
white	*Pinus strobus*
Prickley ash	*Xanthoxylum americanum*
Raspberries	*Rubus strigosus*
Red pine shoot blight	*Siroccus strobilinus*
Root rot	*Fomes annosus*
Roses	*Rosa spp.*
Scleroderris	*Scleroderris lagerbergi*
Spruce, black	*Picea mariana*
white	*Picea glauca*
Sweetfern	*Comptonia peregrina*
Animals	
American bald eagle	*Haliaeetus leucocephalus*
Bark beetle	*Ips pini*
Deer	*Odocoileus virginianus*
European pine shoot moth	*Rhyacionia buoliana*
Hare	*Lepus americanus*
Jackpine budworm	*Choristoneura pinus*
Mice	*Microtus pennsylvanicus*
Pine root collar weevil	*Hylobius radicis*
Pine tussock moth	*Olene plagiata*
Pine webworm	*Tetralopha robustella*
Porcupine	*Erethizon dorsatum*
Saratoga spittlebug	*Aphrophora saratogensis*
Sawflies	*Neodiprion spp.*
White grubs	*Phyllophaga spp.*
White pine weevil	*Pissodes strob.*
Zimmerman pine moth	*Dioryctria zimmermani*

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key – out of the reach of children and animals – and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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Provides a key for the resource manager to use in choosing silvicultural practices for the management of red pine. Control of stand composition and growth, regulating the forest, and control of stand establishment for timber production, water, wildlife, and recreation are discussed.

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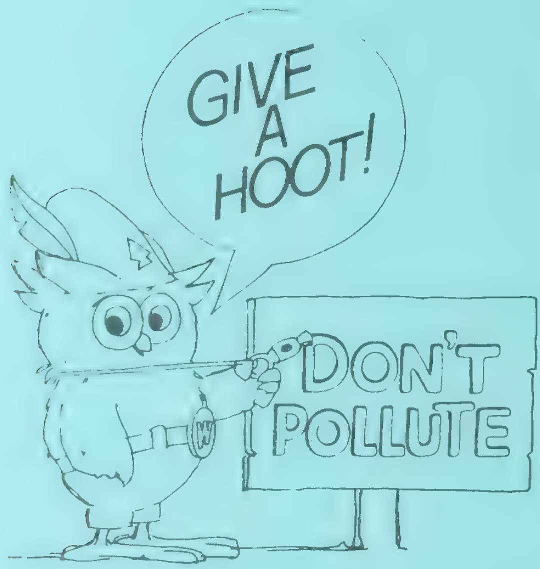

Help save the birds, animals and flowers.

manager's handbook for

BLACK SPRUCE IN THE NORTH CENTRAL STATES

GENERAL TECHNICAL REPORT NC-34

NORTH CENTRAL FOREST EXPERIMENT STATION   FOREST SERVICE   U.S. DEPARTMENT OF AGRICULTURE

CONTENTS

BLACK SPRUCE IN THE NORTH-CENTRAL STATES[1]

William F. Johnston, *Principal Silviculturist*
Grand Rapids, Minnesota

SILVICAL HIGHLIGHTS

The black spruce[2] type occupies 2 million acres of commercial forest land in the northern Lake States; two-thirds of this total occurs in Minnesota. Black spruce grows mainly on organic soil, where its growth rate is related to the amount of nutrients received from ground water or precipitation. Black spruce grows mainly in pure stands but may also be mixed with tamarack, northern white-cedar, and balsam fir on organic soil and with other conifers and various hardwoods on mineral soil. Black spruce stands are brushy on the best sites, especially on organic soil.

Black spruce stands 40 or more years old have a nearly continuous seed supply because the persistent cones shed seed for at least 4 years after ripening and seed crops seldom fail. Seedling establishment requires a moist seedbed free from competing vegetation. Establishment is generally successful on slow-growing sphagnum moss or where the surface layer is removed by fire or compacted as in skid roads. Vegetative reproduction by layering is common on the poorer sites on organic soil.

Most black spruce stands in the Lake States originated after wildfires and so are, or once were, even-aged. In areas having no major disturbance for a century or more, black spruce stands become uneven-aged because new trees begin to fill in as overstory trees die. However, these new trees grow much faster in open areas than under a living overstory.

The main damaging agents of black spruce are wind, eastern dwarf mistletoe, and impeded drainage. Uprooting or breakage is a problem when older stands are opened by partial cutting because black spruce has a shallow root system and butt rot is common in older trees. Mistletoe, which produces "witches' brooms", is the most serious disease of black spruce. Other pests seldom cause serious damage. Drainage impeded by roads and beaver has killed black spruce or reduced its growth on thousands of acres of organic soil.

MANAGEMENT OBJECTIVES AND NEEDS

The usual objective in managing the black spruce type is to produce a high sustained yield of pulpwood as efficiently as possible without adversely affecting other forest values. For this objective, the type can probably be managed best in fairly large, even-aged stands, similar to virgin stands. Such management should produce stands that are well suited for efficient cultural operations and mechanized harvesting. The poorest sites, however, should be managed mainly for Christmas trees. Although limited, practices to enhance wildlife habitat, water, and esthetics should be applied to the extent they have been developed.

The demand for black spruce pulpwood is expected to remain high, so satisfactory stocking of reproduction needs to be obtained promptly after harvesting. This is usually possible by carrying out the practices recommended here. However, little information exists on the costs and returns of these practices. Relative costs are given for a few alternatives, but most economic decisions will have to be based on the particular situation and the manager's experience and judgment. There is a special need to obtain reproduction after harvesting brushy stands, which occur on the most productive sites. If not stocked early with trees, these areas convert to lowland brush and become difficult and expensive to reforest.

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[1] *This handbook supersedes Johnston, William F. 1971. Management Guide for the Black Spruce Type in the Lake States. USDA For. Serv. Res. Pap. NC-64.*

[2] *For scientific names of plants and animals, see Appendix, p. 16.*

KEY TO RECOMMENDATIONS

Recommendations for managing black spruce stands are given in the following key, which contains a series of alternative statements about various stand conditions. The statements include references to the text where these conditions are discussed. So, with accurate knowledge of a stand, the resource manager can find out the recommended practices.

Starting with the first pair of like-numbered statements, select the one statement that better describes the stand in question and obtain a final recommendation, a partial recommendation plus a number, or a number alone. If a number is given, repeat the selection process until a final recommendation is reached. The overall recommendation is the sum of the partial recommendations arrived at while going through the key.

1. **Site index less than 25** . . . . GROW CHRISTMAS TREES
   See "Christmas Trees", p. 10
1. **Site index 25 or more** . . . . GROW PULPWOOD . . 2
   See "Site Productivity", p. 3
   2. **Stand immature** 3
      See "Rotation", p. 3
   2. **Stand mature** . . . . CLEARCUT STAND . . 6
      See "Clearcutting Methods", p. 5 and "Wind", p. 9
3. **Black spruce satisfactorily stocked** 4
   See "Intermediate Treatment", p. 4
3. **Black spruce understocked or overstocked** . . . .
   4. **Spruce severely suppressed by shrubs/hardwoods** . . . . RELEASE . .
      See "Intermediate Treatment", p. 4
   4. **Spruce not or slightly suppressed by shrubs/hardwoods** . . . .
5. **Witches' brooms absent or inconspicuous** . . . . CHECK IN 10 YEARS
   See "Dwarf Mistletoe", p. 9
5. **Witches' brooms readily noticeable** . . . . TREAT INFECTED AREAS
   6. **Witches' brooms absent or inconspicuous** . . . .
      See "Dwarf Mistletoe", p. 9
   6. **Witches' brooms readily noticeable** . . . . BROADCAST BURN SLASH (see p. 15) . . 1
7. **Residual stems abundant** . . . .
   See "Residual Stems", p. 6
7. **Residual stems scarce** 1
   8. **Black spruce a major component** . . . .
      See "Residual Stems", p. 6
   8. **Black spruce a minor component** . . . . BROADCAST BURN SLASH (see p. 15) . . 1
9. **Spruce less than 50 years old and in good health** . . . . SAVE RESIDUAL STEMS
   See "Residual Stems", p. 6
9. **Spruce 50 or more years old, or in poor health** . . . . BROADCAST BURN SLASH (see p. 15) . .
   10. **Brush absent or inconspicuous** . . . .
       See "Brush", p. 6
   10. **Brush readily noticeable** . . . . BROADCAST BURN SLASH (see p. 15) . .
11. **Sphagnum seedbeds well distributed** . . . .
    See "Seedbeds", p. 7
11. **Sphagnum seedbeds poorly distributed** . . . . BROADCAST BURN SLASH (see p. 15) . .
    12. **Slash cover light** . . . . SPREAD SLASH EVENLY, USE NATURAL SEEDING
        See "Slash Cover", p. 7
    12. **Slash cover heavy** . . . . SKID FULL TREES, USE NATURAL SEEDING; BROADCAST BURN SLASH (see p. 15) . .
13. **Seed source within range** . . . . USE NATURAL SEEDING
    See "Clearcutting Methods", p. 5 and "Natural Seeding", p. 8
13. **Seed source out of range** . . . . USE DIRECT SEEDING
    See "Direct Seeding", p. 9

TIMBER MANAGEMENT CONSIDERATIONS

Controlling Growth

Site Productivity

The black spruce type is found mainly on organic soil in the Lake States, but it also occurs on mineral soil. Growth rate varies greatly; height of dominant trees at 50 years ranges from about 45 feet on the best sites to less than 15 feet on the poorest. Mature stands on good sites commonly yield 3,000 cubic feet (entire stem) or 30 cords per acre for trees 3.6 inches d.b.h. and larger. In contrast, many stands on poor sites never produce merchantable quantities of pulpwood. (See Appendix for site index curves, yield, and net annual growth of black spruce stands.)

Most organic soil sites are extensive areas on gently sloping glacial lake beds or smaller filled lakes associated with the Laurentian Shield, pitted outwash plains, and moranic areas. On both lake-bed and filled-lake sites, the growth rate of black spruce is related to the surrounding ground water flow system. The best sites occur where the soil water is continuous with the regional ground water system and thus is enriched by nutrients flowing from mineral soil areas. The poorest sites occur where the soil water is "perched" above and thus is separated from this regional system. The fertility of these sites depends mainly on precipitation, which is relatively low in nutrients.

Degree of decomposition and botanical origin of the upper horizons of organic soil are good guides to site productivity, whereas total depth and pH are poor guides by themselves. The best sites have moderately well decomposed organic soil that contains much partially decayed wood and is dark brown to blackish. However, the upper 6 inches may be poorly decomposed sphagnum or other mosses, especially in old stands. The poorest sites have poorly decomposed sphagnum, 2 to 5 feet or more thick, that is yellowish brown.

The growth rate of black spruce could undoubtedly be increased on organic soil sites in the Lake States by draining and fertilizing, but specific practices are presently lacking. They have not been developed mainly because the region's extensive upland forests produce sufficient timber, and probably at a higher economic return than lowland forests. However, with the increasing value of black spruce pulpwood and the greater demands on land use in upland forests, there may be a need in the future to develop effective and environmentally acceptable ways to drain and fertilize organic soil sites.

The black spruce type is common on mineral soil only on the Laurentian Shield in northeastern Minnesota and in a few isolated areas of upper Michigan. Here black spruce grows on gravelly and bouldery loam and on shallow soil over bedrock, where it usually is mixed with other species, but occasionally forms a pure type. Growth is best where the slope is gentle and moisture is plentiful, either from a shallow water table or seepage. South of the Shield, black spruce is occasionally found on sandy soil with a high water table.

Rotation

Black spruce stands are usually considered mature and ready to harvest for pulpwood when their mean annual growth in cords peaks. The rotations at which this occurs for trees 3.6 inches d.b.h. and larger can be determined from figure 1 for various stand ages and basal areas. These rotations apply to all site indexes and are similar for cubic feet.

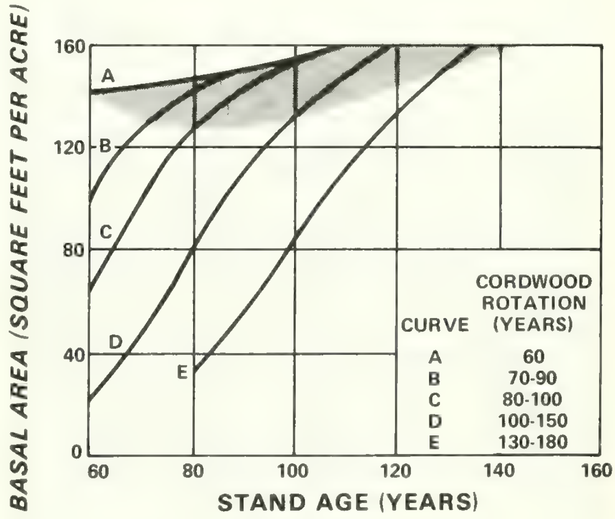

Figure 1. — *Rotations for black spruce stands by stand age and basal area. Adapted from Perala 1971.*

To determine the cordwood rotation for any stand, locate the point where its present age and basal area intersect in figure 1 and then use the following guidelines:

1. If the point is *below* the shaded zone, the stand has not yet reached the recommended rotation. To determine this rotation, select the curve nearest the point and find the rotation range listed for that curve in figure 1. Where the point is between two curves, the rotation range can be determined more precisely by projecting the point upward between the curves and noting at what ages it enters and leaves the shaded zone.

Stands whose basal areas fall well below curve E have poorly stocked overstories that should probably be harvested as soon as possible because these stands would have rotations of 160 to 180 years. Unless a suitable understory remains to form a new stand, black spruce should be rapidly reproduced to full stocking (see p. 2).

2. If the point is *in* the shaded zone, the stand is at the recommended rotation and can be harvested. The range of this rotation is determined the same way as explained in 1.

3. If the point is *above* the shaded zone, the stand is already past the recommended rotation and should be harvested and reproduced as soon as possible.

The rotations recommended here have a range because the mean annual growth has practically the same maximum for a number of years. Therefore, the manager has considerable flexibility in selecting a suitable rotation, at least in terms of growth. Further, figure 1 shows that the rotations are shorter for stands with high basal areas than for those with low basal areas, or that rotations increase as basal area decreases. However, except for excluding trees smaller than 3.6 inches d.b.h., the rotations do not consider tree size. Therefore, excessively dense stands may require longer rotations before yields from merchantable trees are large enough for efficient harvesting.

Of course, factors other than maximum mean annual growth and tree size should be considered in selecting a suitable rotation. The presence of, or risk involved with, some of black spruce's damaging agents, especially wind and dwarf mistletoe, will tend to shorten the rotation (see p. 9). Butt rot, which can lead to wind breakage, becomes common after about 100 years in stands on organic soil. This rot becomes serious enough in stands on mineral soil that their rotation should usually not exceed 70 years. To further help the manager select a suitable rotation for a certain stand, yield and growth at various ages are given in the Appendix by site index and basal area.

Intermediate Treatment

Little research or experience is available on managing immature stands of black spruce. Desirable stand densities for various ages and sites are not known for optimum pulpwood growth under present utilization standards. Thinning of overstocked stands in the sapling and pole stage is not recommended for black spruce due to the low economic return and risk of increasing wind-caused mortality.

In seedling stands a milacre[3] stocking of 60 percent or more is considered satisfactory if the trees are *established* (at least 6 inches tall and healthy). Practica methods do not presently exist for establishing blac spruce in understocked stands, except to leave seed-bearing trees so that spruce can gradually reproduce b natural seeding. Seedling stands are probably over stocked when they exceed 10,000 trees per acre. Suc stands should be prevented by controlling natural o direct seeding, as discussed on pages 8 and 9.

Although it grows faster in full sunlight, black spruc is tolerant of shade and on most organic soil sites it wi eventually grow above competing shrubs or hardwood However, slow growth and understocking result whe black spruce is severely suppressed by such vegetatio for several years, as often happens on the best site Under these conditions spruce should be released *befo* its growth and ability to respond are reduced too muc

Aerial herbicide spraying is probably the most pra tical way to kill back overtopping shrubs and har woods. A low volatile ester of 2,4-D[4] is effective speckled alder, black ash, quaking aspen, paper birc and willow; whereas a 50-percent mixture with 2,4,5-T recommended if red maple and balsam poplar are t main species to control. Use a total rate of 3 pounds ac equivalent in at least 4 gallons of water per acre. Spr in early August, or when the new growth of black spru has hardened off and yet shrubs and hardwoods are st susceptible.

Herbicide spraying should be done carefully, followi all pertinent precautions and regulations. It is particul ly important not to contaminate open water wi herbicide, so do not spray vegetation around the borde

[3] *A milacre is 1/1,000 acre, usually 6.6 feet square.*

[4] *See Pesticide Precautionary Statement, p. 17.*

of ponds, lakes, and watercourses. These guidelines will minimize the risk of adverse environmental effects on organic soil sites.

Controlling Establishment and Composition

Clearcutting Methods

For several reasons mentioned elsewhere in this handbook, clearcutting, or felling of *all* trees, is the best method for harvesting and reproducing black spruce. The shape and size of a clearcut area depend mainly on whether broadcast burning of slash is recommended in the key, size and windfirmness of stand, seed supply, and economic considerations.

If broadcast burning is recommended, its cost per acre can be reduced substantially by clearcutting large patches (40 acres or more) rather than progressive strips. Cost of harvesting and later cultural operations also tends to be lower on such patches than on strips. However, clearcutting of large patches (or entire stands less than 40 acres) should usually be followed by direct seeding (see p. 9), whose cost may offset the above savings. Since it is sometimes difficult to obtain enough seed of acceptable provenance at reasonable cost, the manager should consider carefully whether to clearcut large patches that require direct seeding[5] or progressive strips that are seeded naturally (figs. 2 and 3).

Progressive strips can be applied best in large stands that are windfirm and do not require broadcast burning. The strips should probably be perpendicular to, and progress toward, the prevailing wind direction to maximize seed dispersal and minimize wind damage.

Natural seeding of black spruce can be relied on up to 4 chains (1 chain = 66 feet) from the windward side of a mature stand and up to 2 chains from the leeward side. Thus a strip perpendicular to the prevailing wind direction can be up to 6 chains wide with natural seeding from both sides, or 4 chains wide with seeding only from the windward side. Also, the outer portion of large patches can often be reproduced by natural seeding, thus importantly reducing the area requiring direct seeding.

[5] *Planting may be better on upland sites.*

Stands as small as 20 acres can be clearcut and broadcast burned in strips 3 chains wide if desired. Of course, the shape of such stands may be the main factor in deciding which way to orient the strips. Because harvesting and other costs depend so much on the particular situation, the manager must decide what minimum size of clearcut area is still economical.

Ways to make new harvest areas look better are discussed under "Esthetics" (p. 11).

Figure 2. – *This 98-acre patch was clearcut, broadcast burned, and direct seeded. Note the unburned, slash-free alley next to the surrounding forest.*

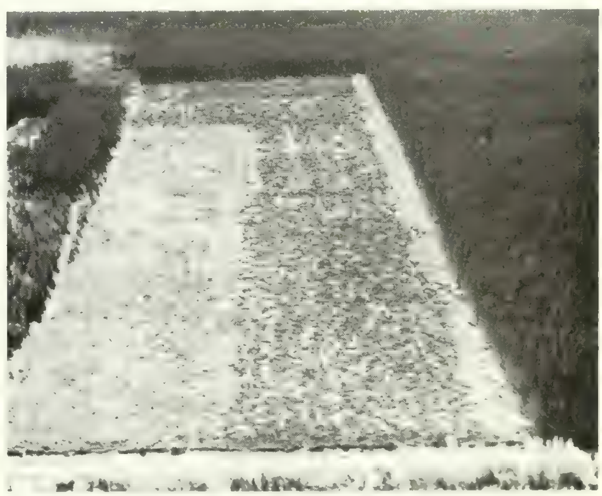

Figure 3. – *These two strips, each about 4 chains wide and 1/4 mile long, were clearcut and broadcast burned 4 years apart; future strips will progress into the mature stand at the right. Note the unburned, slash-free alley next to the stand.*

Residual Stems

These are trees of any size down to 6 inches tall that are expected to or do survive clearcutting. They may be of any species or age, and of seedling or vegetative origin. Residual stems are "scarce" if they or their reproduction, especially by vegetative means, will not become dense enough to severely suppress black spruce reproduction. Although they can be easily overlooked, it is important to realize that a few mature trees per acre of certain species sometimes produce many seeds, suckers, or sprouts.

Residual stems should be relied on to reproduce a stand only if relatively young and healthy black spruce stems are or will be predominant (at least 50 percent of basal area). Such stems are arbitrarily defined as being less than 50 years old and having well-developed crowns. In contrast, many of the black spruce stems remaining after clearcutting are 50 or more years old or have poorly developed crowns. Old stems also tend to be of layer origin, which often results in poor form. Some old or unhealthy trees may grow satisfactorily after clearcutting, but young seedlings are preferred for reproducing black spruce.

Therefore, residual stems should be saved to reproduce a stand only if: (1) 60 percent or more of the milacres in the clearcut area will contain at least one young and healthy black spruce *after* harvesting and (2) the cost of saving such stems does not exceed the cost of obtaining new spruce reproduction of equal density *and* size. Obviously, the stand must be harvested carefully and slash removed where it covers needed stems.

Residual stems should be killed if suitable black spruce are not present to form a new stand. This is most important where these stems are abundant or will reproduce abundantly after clearcutting. Broadcast burning of slash is an efficient way to kill residual conifers, especially where many are of seedling or sapling size. Burning will also kill back hardwoods, but herbicides are more effective on those that reproduce mainly from suckers or sprouts.

Aerial herbicide spraying should be used if there are many residual hardwoods per acre, whereas scattered trees and stumps should be treated individually. To minimize suckering and sprouting, herbicide should be applied to a frill girdle around the base of uncut hardwoods immediately after full leaf development. An effective herbicide is a low volatile ester of 2,4,5-T at 8 pounds acid equivalent (ae) per 100 gallons of No. 2 fuel oil solution, or the amine salt of 2,4-D or 2,4,5-T at 1 milliliter of a 50-percent water solution per inch of tree diameter. Uncut trees can be killed without girdling by basal spraying with Tordon 155[6] (a combination of picloram and 2,4,5-T) at 10 pounds ae per 100 gallons of fuel oil solution. Fresh hardwood stumps can be wet thoroughly with Tordon 101 (a combination of picloram and 2,4-D) at 5 pounds ae per 100 gallons of water solution to control suckering and sprouting.

Brush

Black spruce stands are usually brushy on the best sites on organic soil. An understory of tall shrubs such as speckled alder and red-osier dogwood is typical (fig. 4). In contrast, stands on medium to poor sites are nonbrushy and have only some low shrubs such as Labrador-tea and leather-leaf (fig. 5).

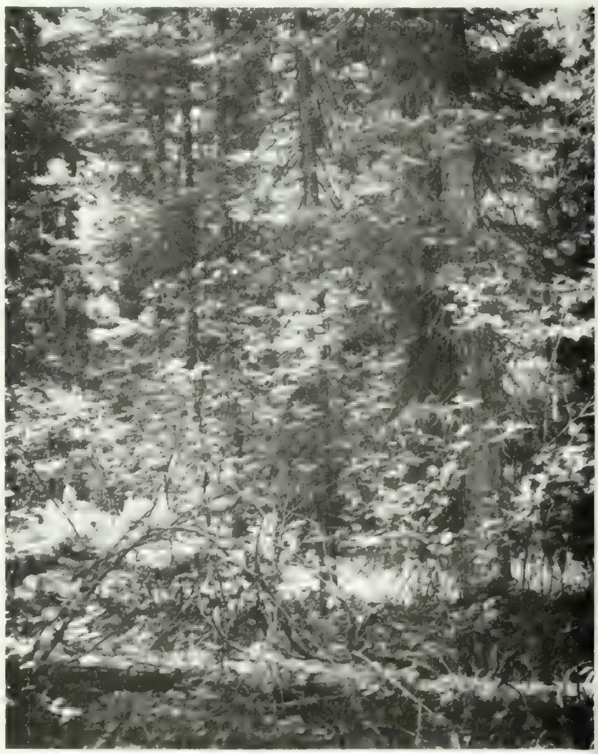

Figure 4. – *This brushy stand of black spruce is typical of those occupying the best sites on organic soil. As shown here, a readily noticeable understory of tall shrubs such as speckled alder is usually present.*

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[6] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

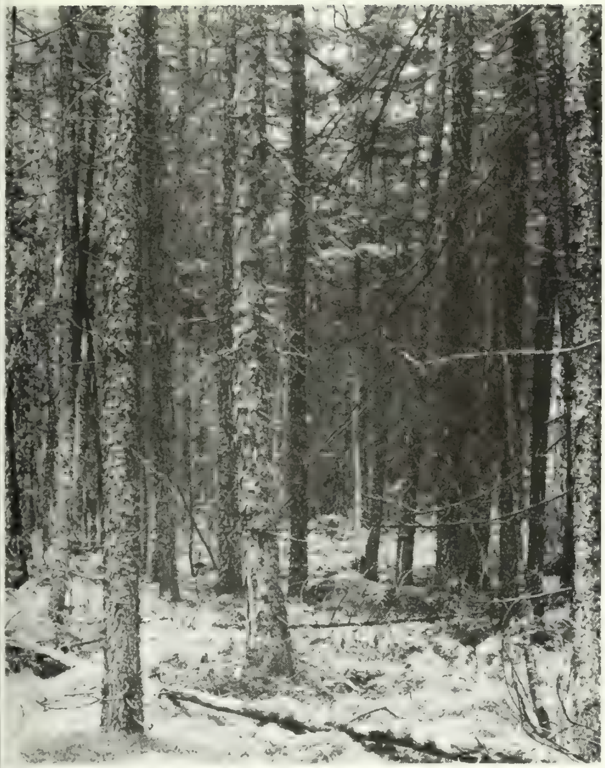


Figure 5. — *This nonbrushy stand of black spruce is typical of those occupying medium to poor sites on organic soil. As shown here, practically no understory is present except for some low shrubs such as Labrador-tea.*

Brush density is difficult to judge because it usually increases greatly after clearcutting. Also, brush is less noticeable when the leaves are off. Therefore, brush should be rated "absent or inconspicuous" only after inspecting the stand carefully — preferably when the leaves are on. Brush that is "readily noticeable" should be controlled because it will probably become dense enough to suppress black spruce reproduction.

Broadcast burning of slash is recommended on brushy sites because it has resulted in good initial establishment of black spruce, especially where ample natural seeding was available. Even so, brush and other competing vegetation, particularly grasses and sedges, overtop many seedlings and reduce their growth within a few years on burn areas. Therefore, black spruce reproduction on brushy sites will usually need release as discussed and prescribed under "Intermediate Treatment" (p. 4).

Seedbeds

Seedling establishment requires a moist but unsaturated seedbed free from competing vegetation. Establishment is generally successful if the surface layer is: (1) removed, either by fire or machine; (2) compacted, as in a skid road; or (3) composed of living sphagnum moss. Most types of sphagnum moss are good seedbeds, although some types outgrow black spruce seedlings and smother them. Other mosses, particularly the feather mosses, dry up and die after clearcutting and become extremely poor seedbeds (fig. 6). Thus seedbed conditions are usually much improved by removing or compacting such mosses.

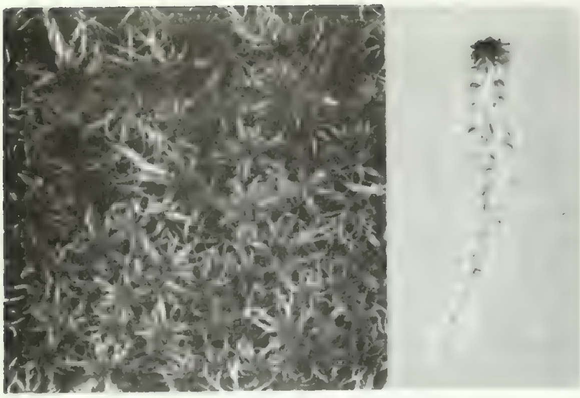
Sphagnum seedbeds are "well distributed" when exposed patches of sphagnum moss occur in at least 60 percent of the milacres in the clearcut area, or at a square spacing not exceeding about 10 feet.

Slash Cover

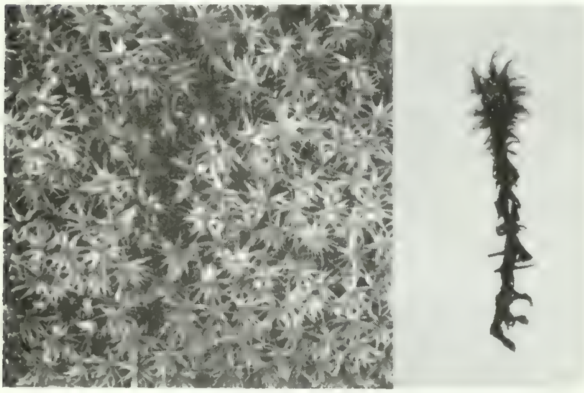
This is "heavy" when slash hinders satisfactory reproduction by burying either suitable residual stems or good seedbeds such as sphagnum moss. Slash cover is also heavy when it creates an important fire hazard. However, the risk of fire is low on most black spruce areas because they do not dry up much and there is little contact with human activities.

Slash should be broadcast burned for all conditions where this is recommended in the key, including where a heavy cover of slash is *already* on the ground. However, if slash cover is the only problem expected, then full-tree skidding can be used. This is because recent research indicates that stands harvested by full-tree skidding, with branches and tops intact, leave only a light cover of slash when felling and skidding are done with reasonable care. All trees should be felled as the harvesting progresses, leaving stumps as low as possible to minimize obstacles that would break off branches and tops during skidding. Also, the trees should be felled into the open rather than into the stand where more breakage would occur.

The overall cost of slash disposal should be less by full-tree skidding than by broadcast burning if most trees are merchantable. Skidding should be particularly advantageous on small areas because they have the highest burning cost per acre. Of course, slash disposal is usually not needed in poorly stocked stands when the slash is spread evenly.



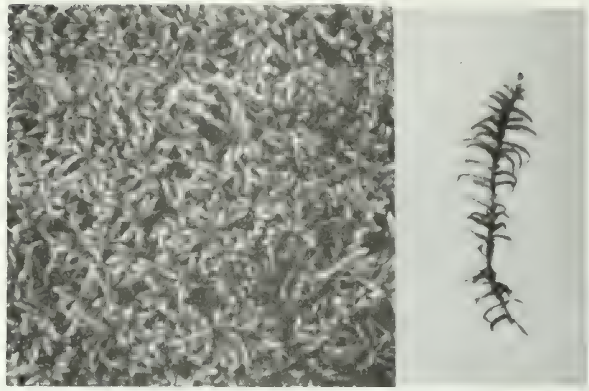
Sphagnum spp.



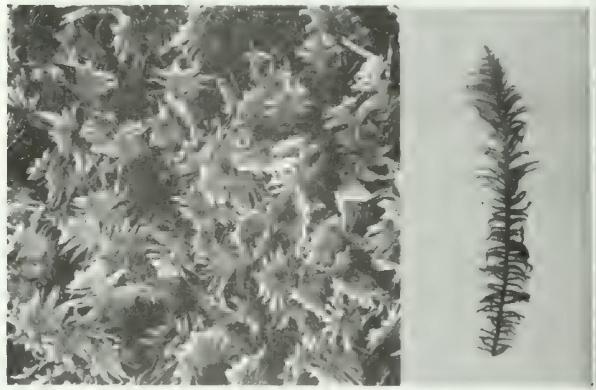
Dicranum polysetum

Figure 6. – *These mosses are common seedbeds in black spruce stands, particularly on nonbrushy sites. All except sphagnum make poor seedbeds because they dry up and die after clearcutting. The photos all have the same scale; the individual plants are about 3 inches tall.*

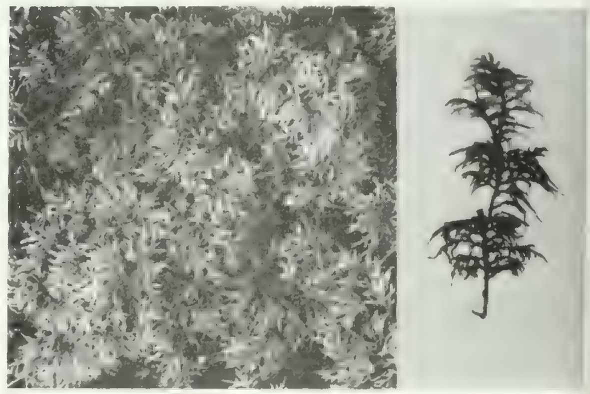
FEATHER MOSSES



Pleurozium schreberi



Ptilium crista-castrensis



Hylocomium splendens

Natural Seeding

Black spruce is a dependable seed producer. A mature stand produces an average of perhaps 200,000 seeds – about 8 ounces – per acre per year. Although most of this seed falls in or near the stand, reproduction surveys indicate that a sufficient amount is dispersed far enough to effectively reforest an adjacent clearcut area of substantial size (see p. 5).

Natural seeding of black spruce, especially on nonbrushy sites, often results in new stands that are too dense for optimum pulpwood growth under presen utilization standards. To minimize this problem, th manager should survey the reproduction about 3 year after site preparation and if stocking is satisfactory (se p. 4), the adjacent area (strip or stand) of matur spruce should be clearcut to eliminate further seedin into the new stand. When this cutting removes all matur spruce within seeding range (see p. 5), the area can b seeded artificially after broadcast burning, or perhap

naturally by seed dispersed before and during full-tree skidding.

Many of the common tree associates of black spruce reproduce on clearcut areas, especially on slash-burned seedbeds. Tamarack reproduces well after broadcast burning on organic soil sites if even a few seed-bearing trees are within 3 chains. Although it is usually outnumbered by black spruce, tamarack grows faster and so will probably be an important component of the new stand. This means that managers who want pure stands of black spruce should harvest or otherwise kill all seed-bearing tamaracks within 3 chains of clearcut areas *before* burning. Seeding from such trees could also be avoided by clearcutting large areas whose interiors are beyond the seeding range of tamarack.

Quaking aspen and paper birch not only reproduce well on slash-burned seedbeds on organic soil sites, but also fairly well on unburned seedbeds such as those resulting from full-tree skidding. These trees have much greater seeding ranges than tamarack, so it is probably impractical to substantially reduce their natural seeding. Fortunately, aspen and birch are not expected to severely suppress black spruce except on the best sites. Here herbicide spraying may be necessary to release the spruce as discussed and prescribed under "Intermediate Treatment" (p. 4).

Direct Seeding

When deciding whether or not to clearcut large areas that require direct seeding, the manager should find out if he can obtain enough seed of acceptable provenance at reasonable cost.

Black spruce has generally been direct seeded at a rate of about 4 ounces (100,000 seeds) per acre to obtain a milacre stocking of at least 60 percent. This has sometimes resulted in overstocking, so 2 to 3 ounces of seed per acre should be adequate on well-prepared sites. However, the manager should check the resulting reproduction success before using this lower rate on a large scale.

The seed need not be stratified but probably should be treated with Arasan, an approved and effective bird repellent and fungicide. Sowing should be done between March and mid-May of the first year following burning. A hand seeder with filler such as fine-textured vermiculite is efficient for seeding small areas. Aircraft or snowmobiles are more efficient for seeding large areas.

Controlling Damaging Agents

Wind

Breakage and uprooting of trees by wind are two of the most important causes of mortality in older stands of black spruce. Wind breakage is more frequent in stands with butt rot, which becomes common after about 100 years on organic soil and 70 years on mineral soil. Both breakage and uprooting occur mainly along stand edges exposed to the prevailing wind and in stands opened up by partial cutting. By using the rotations and cutting methods recommended in this handbook, wind-caused mortality should be minimal.

Dwarf Mistletoe

Eastern dwarf mistletoe is the most serious disease of black spruce in the Lake States. If it is present, trees will have "witches' brooms", which are easy to identify (fig. 7). Mistletoe significantly reduces volume growth and eventually kills trees, so it should be controlled, especially on the better sites. This can be done by killing infected trees because mistletoe survives only on living trees and it spreads slowly.

Figure 7. – *These readily noticeable witches' brooms are typical of those occurring in black spruce stands that are heavily infected with eastern dwarf mistletoe.*

The following general guidelines are recommended to help the manager control mistletoe:

1. Reproduce and maintain dense stands because infection spreads more slowly and causes less damage in them than in open stands.

2. Clearcut mature stands whether they have mistletoe or not. However, if witches' brooms are readily noticeable, clearcut not only the infected area but also a surrounding isolation strip of black spruce that appears to be *entirely uninfected*. This is to remove latent infections that cannot be seen. The strip should be at least 1 chain (66 feet) wide and 2 chains are preferable if the margins of the infected area are indistinct.

All infected trees, including advance reproduction and especially any tall unmerchantable stems, must be cut or otherwise killed to prevent new reproduction from becoming infected. Broadcast burning of slash on clearcut areas is highly recommended because it is an effective and economical way to kill all residual trees and to prepare the site for black spruce reproduction. (See Appendix, p. 15, for burning techniques.)

3. Small pockets (5 acres or less) of infected trees can arise in immature stands from mistletoe seed carried inadvertently by birds or small mammals. These pockets should be controlled because they gradually enlarge and are a source of seed for starting new pockets, which can eventually merge with older ones. As in mature stands, all trees (including reproduction) should be killed in the infected pocket and surrounding 1- to 2-chain-wide isolation strip. This can be done by cutting but it is desirable to broadcast burn the slash where feasible.

4. Areas treated for mistletoe and those where witches' brooms are inconspicuous or apparently absent should be checked in 10 years to make sure the disease is under control.

Impeded Drainage

Poorly constructed or maintained roads have kill black spruce or reduced its growth on thousands of ac of organic soil in the Lake States by impeding t normal movement of water. Beaver damming of natu watercourses or man-made drainage ditches has simil effects. Also, pipelines carrying natural gas and petr leum will cause damage unless cross drainage is provide

Road-caused damage can be minimized by constru ing and maintaining adequate collector and dischar ditches, and by using large culverts that are correct positioned and maintained. Removal of beaver dams a judicious control of beaver can avert damage to valuab timber and the unsightliness of dying trees. Pipelin should have cross ditches about every 150 feet or le These ditches can be through the backfill for pipe buri below ground or beneath pipe placed on the surface.

Other Agents

Fortunately, the other damaging agents of bla spruce seldom are serious. Wildfire easily kills bla spruce trees but good fire protection now results in lit loss. During very dry periods fires can burn deeply organic soil and become extremely difficult to put o Needle rusts may discolor and defoliate some tre enough to spoil them for Christmas trees. Insects such the spruce budworm, eastern spruce beetle, and cert sawflies occasionally attack black spruce. Snowsh hares sometimes debark and browse reproduction, a red squirrels can spoil Christmas trees by clippi cone-bearing branches. Black spruce is browsed oc sionally by moose but rarely by white-tailed deer.

OTHER RESOURCE CONSIDERATIONS

Christmas Trees

Extensive stands of black spruce with a site index of less than 25 have supported a sizable Christmas tree industry for several decades, particularly in Minnesota. These Christmas trees, which require special processing to retain their needles, are the top 3 feet of old trees about 20 to 35 feet tall. Since only some trees have suitable tops, the stands are partially cut. Many stands have been cut more than once about 10 years apart when other trees have developed satisfactory tops.

However, harvesting of black spruce Christmas tre has declined greatly in recent years and is now on limited scale. This is apparently because most of t present stands are no longer producing suitable trees f the market, which requires higher quality than it us to. Therefore, the future of black spruce Christmas tre and how to manage for them are uncertain.

The best indications are that a limited market w continue, but that there is considerable potential

expand it by producing better quality trees. The specific requirements for such trees would have to be worked out with industry. However, these trees could probably be grown faster and more efficiently if management is concentrated on less extensive areas where the site is somewhat better than in present stands, or is improved by a limited amount of drainage and perhaps fertilization. It is also possible that some of the stands that were cut earlier will produce another crop of Christmas trees in the future.

As in the past, stands that are managed for black spruce Christmas trees in the future should be partially cut about every 10 years. If they are not harvested regularly some trees may become unmarketable. For example, red squirrels can spoil tree form by clipping cone-bearing branches during good seed years. Trees of acceptable quality will usually not be abundant enough to result in overcutting the stand. Since succeeding crops come from the remaining stand, it should be protected as much as possible during each cutting. Fortunately, wind damage is rare because the trees are shorter and more open grown than in pulpwood stands.

Wildlife Habitat

The black spruce type is utilized to some extent by many wildlife species, a few of which are mentioned elsewhere in this handbook. New harvest areas and young stands certainly produce different or more abundant browse and other wildlife food than mature black spruce stands. Therefore, shrubs and hardwoods should not be killed back with herbicide spraying until black spruce reproduction definitely needs release (see p. 4). And even then, all dogwood, willow, quaking aspen, and other hardwoods should not be killed because some mixture of these shrubs and trees with black spruce probably enhances wildlife habitat.

The spruce grouse is of special interest because it depends on the black spruce type for most of its habitat needs. Spruce grouse apparently use noncommercial black spruce sites more than commercial sites, so their habitat may be only moderately affected by timber management. However, spruce grouse habitat can probably be maintained or enhanced on commercial sites by leaving the following kinds of black spruce stands within compartments of 160 acres or less:

1. Mature stands with high basal areas (more than 150 square feet per acre) are important as display habitat for male grouse in late spring. These stands are characterized by little or no undergrowth and a ground cover of feather moss.
2. Young stands of black spruce 10 to 15 feet tall with dense shrub and herbaceous layers are used by female grouse for cover and feeding before and after nesting. Labrador-tea and leather-leaf are usually the dominant species of the undergrowth and sphagnum moss of the ground cover.
3. Mature spruce stands with moderate basal areas (80 to 100 square feet per acre) and little or no undergrowth, as well as young spruce stands with a dense shrub cover, are used for nesting.
4. Black spruce stands with trees 20 to 60 feet tall and about 150 square feet of basal area per acre are important habitat for both sexes in fall and winter.

Therefore, to provide the overall habitat needs of spruce grouse, harvesting of black spruce should be planned carefully so that each compartment will have the kinds of stands just described. This can be done by clearcutting in strips or patches that are well distributed in the compartment and over time. Further, the objective should be to break up extensive, pure stands of black spruce because transition zones with other forest types and some mixture of tamarack seem to benefit spruce grouse. Recording the kind and density of undergrowth in spruce stands during forest inventory would aid the manager interested in coordinating timber and grouse management.

Water

Current research findings indicate that clearcutting black spruce in strips or large patches, or broadcast burning the slash changes the quantity of water little on organic soil sites. However, if a stream flows from or through a clearcut area, the water will have a higher concentration of certain nutrients for a few years with or without burning. Whether or not this increase in nutrients will have an important effect downstream, especially in lakes, is still unknown.

Esthetics

The manager can minimize the impact of harvesting on the esthetic appeal of the black spruce type by: (1) having harvest boundaries follow natural site or forest type lines and (2) removing heavy slash cover and otherwise leaving harvest areas neat. Slash can either be broadcast burned or removed by full-tree skidding and burned at the landing.

Yield and Growth

The information presented here enables the manager to estimate the present yield and future growth of any black spruce stand given its site index, age, and basal area. Site index is obtained from the average age (total) and average height (total) of dominant and codominant trees (fig. 8). Yield and growth are given in *total cubic feet* (gross peeled volume of entire stem) (tables 1 and 2) and in *cords* (gross rough volume to a variable top d.i.b. of not less than 3.0 inches) (tables 3 and 4). All values are for trees 3.6 inches d.b.h. and larger. Growth is periodic *net annual* increment, which takes into account ingrowth and mortality.

The yield of any stand can be projected by adding present yield and future growth. However, growth should not be calculated for more than a 10-year period. The following example shows how to use the tables: What is the estimated cubic-foot yield in 5 years of a stand with site index 35, age 140 years, and basal area 110 square feet per acre? First, determine the present yield from table 1; this requires interpolating between the values for 100 and 120 square feet of basal area. b present yield = (2,090 + 2,500) ÷ 2 = 2,295. Seco , determine the net annual growth from table 2 d multiply this by 5 to get the total growth for 5 ye ; (50 + 46) ÷ 2 = 48 and 48 x 5 = 240. Therefore, e stand's yield in 5 years = 2,295 + 240 = 2,535 cubic f .

The manager should use the yield and grov h information in this handbook with caution, especially n mineral soil sites. The site index curves (fig. 8) are ba d on stands that presumably grew on mineral soil sites d organic soil sites, so these curves should be satisfact y for both kinds of sites. Also, the yields (tables 1 and) should be reasonably accurate for both kinds of s s because various basal areas can be used to take care f any differences in stand density. However, the values r growth (tables 2 and 4) should be used with considera e caution on mineral soil sites because these values e based on data from organic soil sites, which may h e somewhat different growth rates. For more comp e and detailed information on yield and growth, e manager should consult the reference footnoted in e tables.

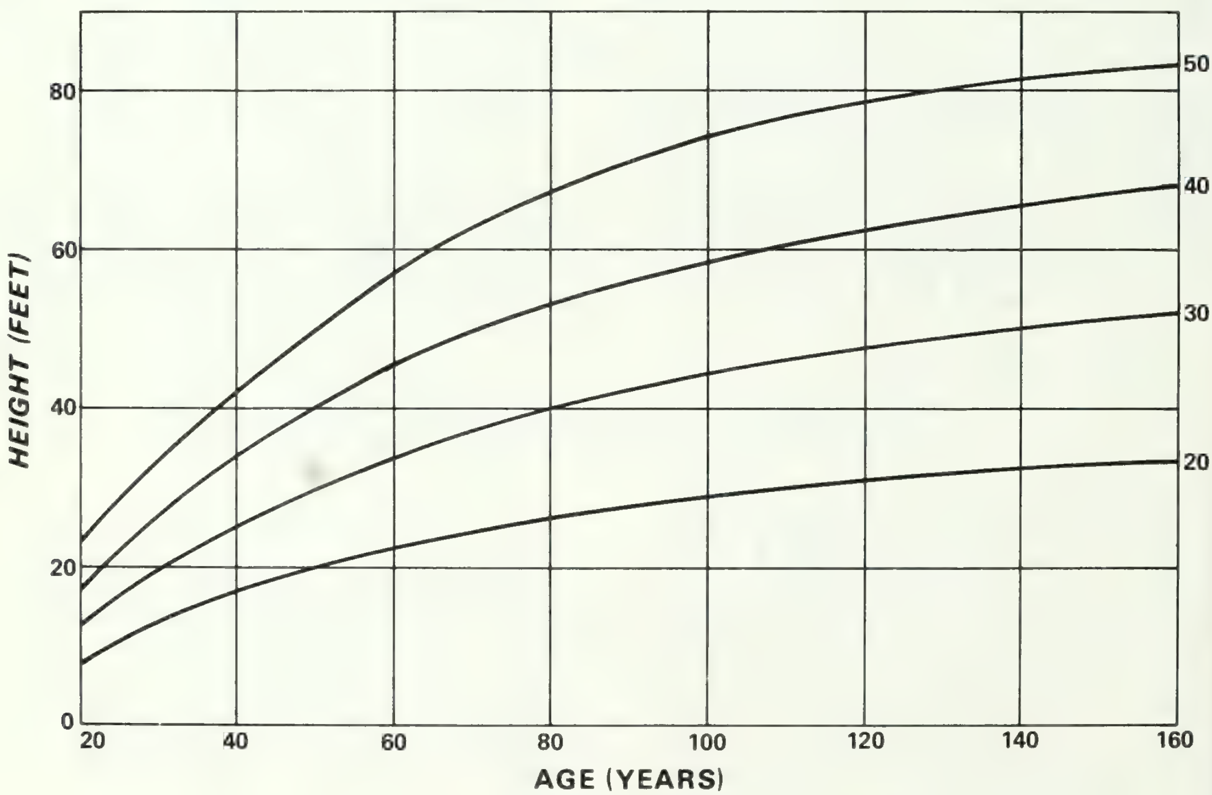


Figure 8. — *Site index curves for black spruce stands. Adapted from Perala 1971.*

Table 1. — *Cubic-foot yield of black spruce stands by site index, age, and basal area*[1]

SITE INDEX 45

Age (years)	Height of dominants and co-dominants (feet)	Basal area per acre (square feet)					
		60	80	100	120	140	160
		Total cubic feet per acre					
60	51	1,360	1,800	2,230	2,660	3,090	--
80	60	1,420	1,870	2,320	2,770	3,220	3,660
100	67	1,450	1,920	2,380	2,840	3,290	3,750
120	71	1,470	1,950	2,420	2,880	3,350	3,810
140	74	1,490	1,970	2,440	2,910	3,380	3,850
160	77	1,500	1,980	2,460	2,940	3,410	3,880
SITE INDEX 35							
60	40	1,170	1,540	1,910	2,280	2,650	--
80	46	1,210	1,600	1,990	2,380	2,760	3,140
100	51	1,240	1,640	2,040	2,430	2,820	3,210
120	55	1,260	1,670	2,070	2,470	2,870	3,260
140	58	1,280	1,690	2,090	2,500	2,900	3,300
160	60	1,290	1,700	2,110	2,520	2,930	3,330
SITE INDEX 25							
60	28	950	1,250	1,560	1,860	--	--
80	33	990	1,310	1,620	1,930	2,240	--
100	36	1,010	1,340	1,660	1,980	2,300	2,610
120	38	1,030	1,360	1,690	2,010	2,330	2,660
140	40	1,040	1,370	1,700	2,030	2,360	2,690
160	42	1,050	1,380	1,720	2,050	2,380	2,710

[1]Values are for trees 3.6 inches d.b.h. and larger. Adapted from Perala 1971.

Table 2. — *Net annual cubic-foot growth of black spruce stands by site index, age, and basal area*[1]

SITE INDEX 45

Age (years)	Basal area per acre (square feet)					
	60	80	100	120	140	160
	Total cubic feet per acre					
60	92	85	68	44	16	--
80	76	74	64	48	26	--
100	66	67	62	50	34	14
120	59	62	60	52	41	25
140	54	58	59	54	46	34
160	50	56	57	55	50	43
SITE INDEX 35						
60	78	73	58	38	14	--
80	65	64	55	41	22	--
100	56	58	53	43	29	12
120	50	53	51	45	35	21
140	46	50	50	46	39	29
160	43	48	49	48	43	37
SITE INDEX 25						
60	64	59	48	31	--	--
80	53	52	45	33	18	--
100	46	47	43	35	24	10
120	41	43	42	36	28	17
140	37	41	41	38	32	24
160	35	39	40	39	35	30

[1]Values are for trees 3.6 inches d.b.h. and larger. Adapted from Perala 1971.

Table 3. — *Cordwood yield of black spruce stands by site index, age, and basal area*[1]

Age (years)	Height of dominants and co-dominants (feet)	Basal area per acre (square feet) 60	80	100	120	140	160
		- - - - - - Cords per acre					- - - - - -
SITE INDEX 45							
60	51	14	18	22	27	31	--
80	60	15	20	24	29	33	38
100	67	16	20	25	30	35	40
120	71	16	21	26	31	36	41
140	74	16	22	27	32	37	42
160	77	17	22	27	32	38	43
SITE INDEX 35							
60	40	10	14	17	20	23	--
80	46	11	15	18	22	25	29
100	51	12	16	19	23	26	30
120	55	12	16	20	24	27	31
140	58	12	16	20	24	28	32
160	60	13	17	21	25	28	32
SITE INDEX 25							
60	28	7	10	12	14	--	--
80	33	8	10	13	15	18	--
100	36	8	11	13	16	18	21
120	38	8	11	14	16	19	22
140	40	9	11	14	17	19	22
160	42	9	12	14	17	20	22

[1]Values are for trees 3.6 inches d.b.h. and larger. Adapted from Perala 1971.

Table 4. — *Net annual cordwood growth of black spruce stands by site index, age, and basal area*[1]

Age (years)	Basal area per acre (square feet) 60	80	100	120	140	160
	- - - - - - - Cords per acre					- - - - - -
SITE INDEX 45						
60	1.0	0.9	0.7	0.5	0.2	--
80	.8	.8	.7	.5	.3	--
100	.7	.7	.7	.6	.4	0.2
120	.6	.7	.7	.6	.5	.3
140	.6	.6	.6	.6	.5	.4
160	.6	.6	.6	.6	.6	.5
SITE INDEX 35						
60	0.7	0.7	0.6	0.4	0.2	--
80	.6	.6	.5	.4	.2	--
100	.5	.6	.5	.4	.3	0.1
120	.5	.5	.5	.4	.3	.2
140	.4	.5	.5	.4	.4	.3
160	.4	.5	.5	.5	.4	.4
SITE INDEX 25						
60	0.5	0.5	0.4	0.3	--	--
80	.4	.4	.4	.3	0.2	--
100	.4	.4	.4	.3	.2	0.1
120	.3	.4	.3	.3	.2	.2
140	.3	.3	.3	.3	.3	.2
160	.3	.3	.3	.3	.3	.2

[1]Values are for trees 3 .6 inches d.b.h. and larger. Adapted from Perala 1971.

Broadcast Burning Techniques

Research and experience in northern Minnesota and upper Michigan have shown that black spruce slash, whether pure or mixed with slash of associated conifers, can be broadcast burned safely, effectively, and economically on organic soil sites. So burning on such sites should be successful throughout the Lake States after resource managers gain some local experience.

If burning is a recommended practice (see p. 2), the area involved must be located and harvested in such a way that it can be burned safely and efficiently. The main requirements for setting up and conducting a successful broadcast burn are:

1. Locate burn area on *undrained* organic soil to avoid deep ground fires that are difficult and expensive to put out. Unless burning is essential for site preparation, slash should be removed by full-tree skidding near drained organic soil, such as along ditches, and near upland sites. Burning near drained organic soil should be done only after the surface soil has been wet down thoroughly. A mineral soil firebreak should be constructed near upland sites.
2. Make edges of burn area smooth and reasonably straight to avoid control problems resulting from sharp angles.
3. Cut all unmerchantable trees near the edge of the burn area.
4. Plan cutting and skidding so as to distribute the slash evenly, thus ensuring that the fire will spread over the entire burn area.
5. Leave a slash-free alley about 1/2 chain wide around the perimeter of the burn area.
6. Burn slash within a year after harvesting.
7. Burn when conditions will ensure consumption of most slash less than 1 inch in diameter (see below).
8. Burn when the wind direction is away from adjacent timber to avoid serious crown scorch or mortality. If the burn area is completely surrounded by timber or the desired wind direction is uncommon, then use center firing when the wind speed is only 0 to 5 miles per hour.

Black spruce slash has been broadcast burned successfully under a wide range of conditions. However, research and experience indicate that burning severe enough to kill back brush or improve nonsphagnum seedbeds requires drier and hotter conditions than burning to just consume slash or kill residual trees, which simultaneously eradicates dwarf mistletoe. Most burning has been done under the following conditions:

Time or weather variable	Burns in general	Severe burns
Time of year	May to October	July to August
Time since rain $\geq$0.1 inch	3 to 10 days	$\geq$7 days
Minimum relative humidity	30 to 60 percent	$<$45 percent
Maximum air temperature	60° to 90°F	$\geq 80^\circ$F
Maximum wind speed	5 to 15 mph	5 to 15 mph

On mineral soil sites, broadcast burning must be severe enough to expose mineral soil if natural or direct seeding is planned. However, local conditions and experience may indicate that mechanical ground preparation such as scarification is more efficient than burning.

Metric Conversion Factors

To convert	*to*	*Multiply by*
Acres	Hectares	0.405
Board feet[1]	Cubic meters	0.005
Board feet/acre[1]	Cubic meters/hectare	0.012
Chains	Meters	20.117
Cords[1]	Cubic meters	2.605
Cords/acre[1]	Cubic meters/hectare	6.437
Cubic feet	Cubic meters	0.028
Cubic feet/acre	Cubic meters/hectare	0.070
Degrees Fahrenheit	Degrees Celsius	[2]
Feet	Meters	0.305
Gallons	Liters	3.785
Gallons/acre	Liters/hectare	9.353
Inches	Centimeters	2.540
Miles	Kilometers	1.609
Miles/hour	Meters/second	0.447
Number/acre	Number/hectare	2.471
Ounces	Grams	28.350
Ounces/acre	Grams/hectare	70.053
Pounds	Kilograms	0.454
Pounds/acre	Kilograms/hectare	1.121
Pounds/gallon	Kilograms/liter	0.120
Square feet	Square meters	0.093
Square feet/acre	Square meters/hectare	0.230
Tons	Metric tons	0.907
Tons/acre	Metric tons/hectare	2.242

[1] The conversion of board feet and cords to cubic meters can only be approximate; the factors are based on an assumed 5.663 board feet (log scale) per cubic foot and a cord with 92 cubic feet of solid material.

[2] To convert °F to °C, use the formula 5/9 (°F-32) or $\frac{°F-32}{1.8}$.

Common and Scientific Names of Plants and Animals

Plants

Common name	*Scientific name*
Alder, speckled	*Alnus rugosa*
Ash, black	*Fraxinus nigra*
Aspen, quaking	*Populus tremuloides*
Birch, paper	*Betula papyrifera*
Dogwood, red-osier	*Cornus stolonifera*
Fir, balsam	*Abies balsamea*
Labrador-tea	*Ledum groenlandicum*
Leather-leaf	*Chamaedaphne calyculata*
Maple, red	*Acer rubrum*
Mistletoe, eastern dwarf	*Arceuthobium pusillum*
Moss:	
Dicranum	*Dicranum polysetum*
Feather	Main species are: *Hylocomium splendens*, *Pleurozium schreberi*, *Ptilium crista-castrensi*
Sphagnum	*Sphagnum* spp.
Poplar, balsam	*Populus balsamifera*
Rust, needle	*Chrysomyxa* spp.
Spruce, black	*Picea mariana*
Tamarack	*Larix laricina*
White-cedar, northern	*Thuja occidentalis*
Willow	*Salix* spp.

Animals

Beaver	*Castor canadensis*
Beetle, eastern spruce	*Dendroctonus obesus*
Budworm, spruce	*Choristoneura fumiferana*
Deer, white-tailed	*Odocoileus virginianus*
Grouse, spruce	*Canachites canadensis*
Hare, snowshoe	*Lepus americanus*
Moose	*Alces alces*
Squirrel, red	*Tamiasciurus hudsonicus*

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key – out of the reach of children and animals – and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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Sing along with Woodsy and help stop pollution.

manager's handbook for

NORTHERN WHITE CEDAR IN THE NORTH CENTRAL STATES

GENERAL TECHNICAL REPORT NC-35

NORTH CENTRAL FOREST EXPERIMENT STATION FOREST SERVICE U.S DEPARTMENT OF AGRICULTURE

Other Manager's Handbooks are:

- Jack pine – GTR-NC-32
- Red pine – GTR-NC-33
- Black spruce – GTR-NC-34
- Aspen – GTR-NC-36
- Oaks – GTR-NC-37
- Black walnut – GTR-NC-38
- Northern hardwoods – GTR-NC-39

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St. Paul, Minnesota 55108

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CONTENTS

FOREWORD

This is one of a series of manager's handbooks for important forest types in the north central States. The purpose of this series is to present the resource manager with the latest and best information available on handling these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. However, ways to modify management practices to maintain or enhance other values are included where sound information is available.

The author has, in certain instances, drawn freely on unpublished information provided by scientists and managers outside his specialty. He is also grateful to the several technical reviewers in the region who made many helpful comments. In particular, Louis J. Verme of the Michigan Department of Natural Resources provided considerable information on deeryard management in the northern white-cedar type.

The handbooks have a similar format, highlighted by a "Key to Recommendations". Here the manager can find in logical sequence the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbooks. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objective. The manager should also apply new research findings as they become available so that the culture of these important forest types can be continually improved.

NORTHERN WHITE-CEDAR IN THE NORTH CENTRAL STATES

William F. Johnston, *Principal Silviculturist*
Grand Rapids, Minnesota

SILVICAL HIGHLIGHTS

The northern white-cedar[1] type occupies 2 million res of commercial forest land in the northern Lake ates; three-fifths of this total occurs in Michigan. orthern white-cedar grows mainly on organic soil here its growth rate increases as the soil is more composed and has more actively moving soil water. hite-cedar grows in pure stands but more commonly is xed with such trees as balsam fir, black spruce, marack, and black ash. Northern white-cedar may rpetuate itself in pure stands, whereas other trees seem gradually replace it in mixed stands, particularly after turbances. White-cedar lives longer than associated es, reaching ages of 400 or more years on organic soil es.

Northern white-cedar produces good seed crops every o 5 years. Germination and early growth are best on moist seedbeds such as rotten wood, compacted moss as in skid roads, and burned soils. Vegetative reproduction by layering is common on organic soil sites. Northern white-cedar can survive in the shade for several years and yet responds well to release at nearly all ages. So, depending on their history, white-cedar stands can be uneven-aged as well as even-aged.

The main damaging agents of northern white-cedar are wind, deer and hare, and impeded drainage. The relatively shallow root system of white-cedar makes it susceptible to uprooting where trees are exposed to the wind. Short trees and reproduction are often overbrowsed by deer and hare. Drainage impeded by roads and beaver has killed white-cedar and associated trees on thousands of acres of organic soil.

MANAGEMENT OBJECTIVES AND NEEDS

he assumed objective in managing the northern ite-cedar type is to produce at least a moderate tained yield of merchantable timber as efficiently as ssible, while maintaining or increasing the quality and antity of deeryards and other forest values. Some ource managers may be able to concentrate their orts on either timber or deeryards. However, most nagers will need to consider both because timber nagement and deeryard management are usually eparable in the white-cedar type.

herever possible, the type should be managed in ly large, even-aged stands because these are appar-ly best for both timber production and deeryards, are well suited for efficient cultural operations and mechanized harvesting. Practices to enhance other wildlife habitat, water, and esthetics are limited, but will be discussed under "Other Resource Considerations" (p. 10), along with practices for managing deeryards.

The demand for *high quality* white-cedar timber is strong, but the type is being undercut in parts of the Lake States because many mature stands do not have enough such timber for a commercial harvest. Thus there is a need to practice more intensive management that will result in merchantable stands. It is especially important to obtain satisfactory reproduction promptly after harvesting on brushy areas. If not stocked early with trees, these areas convert to lowland brush and become difficult and expensive to reforest.

The white-cedar type is also generally valuable for deeryards in the northern Lake States, but some yards

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[1] *For scientific names of plants and animals, see pendix, p. 16.*

support relatively few or no deer at present because of inadequate shelter, browse, or both. More intensive management is needed to restore traditional yards (past and present), and to produce new ones that will have at least a moderate carrying capacity. Although special funds may be available (or necessary) for some areas, most deeryard management will have to be accomplished in conjunction with timber management. This will require careful long-range planning and coordinated action by timber *and* wildlife managers. An adequate sustained amount of deer shelter and browse, in addition to timber, is possible *only* if the white-cedar type i managed so that stands at different stages of develop ment are properly distributed throughout the forest.

The practices recommended here should result i improved management of the white-cedar type, but littl information exists on their costs and returns. Relativ costs are given for a few alternative practices, but mos economic decisions will have to be based on th particular situation and the manager's experience an judgment.

KEY TO RECOMMENDATIONS

Recommendations for managing northern white-cedar stands are given in the following key, which contains a series of alternative statements about various stand conditions. The statements include references to the text where these conditions are discussed. So, with accurate knowledge of a stand, the resource manager can find out the recommended practices.

Starting with the first pair of like-numbered state ments, select the one statement that better describes th stand in question and obtain a final recommendation, partial recommendation plus a number, or a numbe alone. If a number is given, repeat the selection proces until a final recommendation is reached. The overa recommendation is the sum of the partial recommenda tions arrived at while going through the key.

1\. **Site index less than 25** . . . . MANAGE STAND EXTENSIV
See "Site Productivity", p. 3
1\. **Site index 25 or more** . . . . MANAGE STAND INTENSIVELY

2\. **Stand immature** . . . . DO INTERMEDIATE TREATM
See "Rotation", p. 3 and "Intermediate Treatment", p. 4
2\. **Stand mature** . . . .

3\. **Stand small and provides only adequate deer shelter in vicinity** . . . . OBTAIN/MAINTAIN CLC EVERGREEN CAN
See "Deeryards", p. 10
3\. **Stand large; or stand small but not used, or others available, for deer shelter** . . . .

4\. **Associated trees abundant** . . . . DO PREPARATORY TREATM
See "Preparatory Treatment", p. 5
4\. **Associated trees scarce** . . . . REPRODUCE STAND BY STRIP CUTTING

5\. **First or intermediate set of strips** . . . . USE CLEARCUTTING
See "Reproduction Cutting", p. 6
5\. **Last set of strips** . . . . USE SHELTERW

6\. **Residual stems abundant** . . . .
See "Residual Stems", p. 7
6\. **Residual stems scarce** . . . .

7\. **White-cedar a major component** . . . .
See "Residual Stems", p. 7
7\. **White-cedar a minor component** . . . .

8\. **White-cedar less than 50 years old and in good health** . . . . SAVE RESIDUAL S
See "Residual Stems", p. 7
8\. **White-cedar 50 or more years old, or in poor health** . . . . KILL RESIDUAL STEMS

Slash cover light . . . . SPREAD SLASH EVENLY, USE NATURAL SEEDING
See "Slash Cover", p. 7 and "Natural Seeding", p. 8

Slash cover heavy 10

10. Clearcut strips 1 or 2 chains[2] wide . . . . SKID FULL TREES, USE NATURAL SEEDING
See "Reproduction Cutting", p. 6 and "Slash Cover", p. 7

10. Clearcut strips 3 chains wide . . . . BROADCAST BURN SLASH, USE NATURAL SEEDING
See "Broadcast Burning Techniques", p. 15

TIMBER MANAGEMENT CONSIDERATIONS

Controlling Growth and Composition

e Productivity

he northern white-cedar type is found mainly on anic soil in the Lake States, but it also occurs on eral soil. Growth rate varies greatly; height of inant white-cedar trees at 50 years ranges from at t 40 feet on the best sites to less than 15 feet on the rest. Mature, fully stocked stands of pure white-ar (at least 80 percent) on good sites commonly yield 00 merchantable cubic feet or 50 cords per acre for s 5.0 inches d.b.h. and larger. Much of this volume is ogs and poles, whereas many stands on poor sites duce only small posts. (See Appendix for site index es and yield of white-cedar stands.)

egree of decomposition, botanical origin, and natural nage of the upper horizons of organic soil are good es to site productivity, whereas total depth is a poor e by itself. The best sites have moderately to well mposed organic soil that is derived from woody ts or sedges and is neutral or slightly alkaline. vever, the upper 4 inches on these sites may be ly decomposed sphagnum or other mosses. The best have actively moving soil water and are usually near ms or other drainageways. In contrast, the poorest have poorly decomposed, acid soil that is derived plants such as sphagnum moss throughout the hle root zone. These sites have little water movement ept during snowmelt) and are often far from nageways.

tensive management is recommended where the site dx for white-cedar is less than 25. Stands on such are best suited for producing only small posts and browse, whereas stands on better sites should be aged to produce larger timber and deer shelter (in ion to posts and browse). Clearcutting in strips at tion age, and slash disposal to ensure reproduction, e the only silvicultural practices recommended for sites (see p. 3, 6, 7).

[2]One chain = 66 feet.

The growth rate of white-cedar could undoubtedly be increased on organic soil sites in the Lake States by draining and fertilizing, but specific practices are presently lacking. They have not been developed mainly because the region's extensive upland forests produce sufficient timber, and probably at a higher economic return than lowland forests. However, with the increasing interest in the white-cedar type and the greater demands on land use in upland forests, there may be a need in the future to develop effective and environmentally acceptable ways to drain and fertilize organic soil sites.

The northern white-cedar type is common on mineral soil in the Lake States mainly on seepage areas and limestone uplands. Growth is usually faster than on organic soil, being best on mineral soil that is calcareous and moist but well drained.

Rotation

The best rotation for growing northern white-cedar varies greatly with site productivity and the management objective. White-cedar stands are usually considered mature and ready to harvest for timber when their mean annual growth for the main product peaks. The rotations at which this occurs for two common units of measurement are as follows:[3]

Site index	Merchantable cubic feet	Board feet
	——— (Years) ———	
40 (excellent)	70 to 90	110 to 140
30 (medium)	80 to 100	130 to 160
20 (poor)	100 to 140	130 to 160

These rotations have a range because the mean annual growth has practically the same maximum for a number of years. Therefore, the manager has considerable

[3]*See Appendix for tree dimensions included, site index curves, and timber yield.*

flexibility in selecting a suitable rotation, at least for timber growth. Specific rotations are not given for posts or poles because a stand can yield various numbers and sizes of these piece products. However, if the main objective is to grow poles of a certain length, table 2 in the Appendix shows the number of years required on different sites.

White-cedar stands provide an optimum quantity and quality of browse or shelter for deer at different ages, depending on the site, as follows:[4]

Site index	Approximate Age For Optimum: Browse	Shelter
	——— (Years) ———	
40	25 to 30	$\geq$ 60
30	30 to 40	$\geq$ 100
20	50 to 70	--[5]

In comparing the timber rotations with those for deer shelter (at the same site indexes), it is obvious that little or no optimum shelter will be provided if the stands are managed to maximize merchantable cubic feet. However, if the rotations are extended to maximize board feet, many years of optimum shelter will be provided except on poor sites. Therefore, in areas where the white-cedar type is important for deer shelter, rotations should generally be at least the minimum ones shown for board feet. (See page 10 for more information on managing deeryards.)

Determining a suitable rotation for *mixed* stands is complicated further because several of the main tree species associated with northern white-cedar require shorter rotations. Balsam fir, aspen (quaking and bigtooth), balsam poplar (balm-of-Gilead), and paper birch should generally be harvested at about 50 years on medium sites, whereas red maple and black ash require at least 100 years to produce saw logs. Whether or not harvesting is done at these rotations will depend on the yield and value of these species. Additional recommendations for handling mixed stands are discussed under "Intermediate Treatment".

Of course, factors other than maximum mean annual growth and deer shelter should be considered in selecting a suitable rotation. The presence of, or risk involv with, some of the damaging agents of white-cedar a associated trees may determine the rotation. F example, mature trees are relatively tall and thus more susceptible to uprooting or breakage by wi They also sometimes have butt rot, which can seriou reduce merchantable volume and lead to wind break as the stand becomes older.

Intermediate Treatment

Little research or experience is available on manag immature stands of northern white-cedar. Because i long lived and tolerant to very tolerant of sha white-cedar should eventually become dominant if th is adequate stocking tall enough to survive deer brows (about 15 feet). However, intermediate treatment off an excellent opportunity to improve stand composit and speed up development of both high quality tim and deer habitat. Unfortunately, intermediate treatm often produces little or no immediate return and s can probably be justified only on the best areas timber management, or in key deeryards for wh special funds are provided.

Despite its shade tolerance, white-cedar reproducti grows best in half to full sunlight. Thus its growth (proportion) in immature stands can be increased controlling the usual overtopping shrubs and trees. ' degree to which competing vegetation should be c trolled depends on the management objectives. Un white-cedar timber is the only objective, a mixed st of 50 to 80 percent white-cedar is probably best multiple-use purposes. Pure white-cedar (at least percent) is often neither practicable nor desirable. example, a mixture with valuable pulpwood species s as black spruce sometimes makes management m attractive economically.

The best intermediate treatment depends on composition and merchantability of the compe vegetation. Aerial herbicide spraying is probably most practical way to kill back overtopping shrub hardwoods in young stands. However, little is kn about the sensitivity of northern white-cedar to s spraying and so spraying should be tested before b used on a large scale. A low volatile ester of 2,4-D effective on speckled alder, black ash, aspen, p birch, and willow; whereas a 50-percent mixture 2,4,5-T is recommended if red maple and balsam po

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[4] *Adapted from Verme 1965 and Gevorkiantz and Duerr, 1939, "Volume and yield of northern white cedar in the Lake States," unpublished report on file at North Central Forest Experiment Station, St. Paul, Minnesota.*

[5] *White-cedar does not grow tall enough on poor sites to provide optimum shelter.*

[6] *See Pesticide Precautionary Statement, p. 17.*

e the main species to control. Use a total rate of 3 ounds acid equivalent in at least 4 gallons of water per re. Spray in early August, or when white-cedar has mpleted its new growth and yet shrubs and hardwoods e still susceptible.

Herbicide spraying should be done carefully, following pertinent precautions and regulations. It is particu-ly important not to contaminate open water with rbicide, so do not spray vegetation around the borders ponds, lakes, and watercourses. These guidelines will inimize the risk of adverse environmental effects on ganic soil sites.

n older stands where northern white-cedar or its main ociated trees are merchantable, it may be possible to n commercially or at little cost. Thinning can improve th timber quality and deer use. If the slash is left so at it is available and not an obstacle, white-cedar and rdwoods cut in *winter* provide browse; deer also have ace to move about more easily than in excessively nse, unthinned stands. For optimum deer shelter, ciduous trees (hardwoods and tamarack) should be cut otherwise killed to obtain a closed canopy of ergreens (mainly white-cedar and black spruce). Bal-n fir should be harvested *no later than* 70 years of age cause butt rot makes this species especially susceptible wind breakage after that.

The best available information indicates that middle-ed stands managed for timber can be initially thinned a residual basal area of 130 square feet per acre and n rethinned every 10 years to at least as low as 90 uare feet without affecting growth or mortality. The iter first thinning is needed to maintain maximum owth. Good diameter growth of white-cedar can parently be maintained through repeated thinnings t favor dominant and codominant trees. Research dings also indicate that advance tree reproduction and ubs grow little unless the stand is rethinned to less n 150 square feet per acre (fig. 1).

Therefore, it is generally best not to thin below 150 uare feet of basal area per acre. This provides an portunity to improve the quality of the final harvest l to increase total yield without producing an desirable undergrowth of balsam fir and shrubs, for mple. Such thinning also provides deer shelter rang-from fairly good immediately after thinning to ellent toward the end of the thinning cycle.

eparatory Treatment

he primary purpose of preparatory treatment is to trol associated trees before the final harvest so that

Figure 1. — *Typical stand of northern white-cedar and some black spruce, with an undesirable undergrowth of balsam fir, 10 years after a second thinning to 130 square feet of basal area per acre.*

northern white-cedar will remain predominant in the next stand. Thus associated trees are "scarce" only if their reproduction, especially by vegetative means, will not become predominant. Although they can be easily overlooked, it is important to realize that a few mature trees per acre of certain species sometimes produce many seeds, suckers, or sprouts.

Preparatory treatment, like intermediate treatment, should usually be: (1) aimed at obtaining a mixed stand of 50 to 80 percent white-cedar and (2) limited to stands where intensive management for timber, deer habitat, or both can be justified. Since intermediate treatment tends to reduce the amount of undesirable associated trees, preparatory treatment will have the greatest value in mixed stands that have had no intermediate treatment.

Preparatory treatment should be done at least 5, and preferably 10, years before reproduction cutting to ensure control of undesirable trees. To minimize the establishment and growth of suckers, sprouts, and seedlings from these trees after treatment, it is apparent-ly important to have a residual basal area of about 150 square feet per acre. Hardwoods are usually more important to control than conifers because they repro-duce readily both vegetatively and from seed. Root suckers, such as those of balsam poplar, and stump sprouts are very competitive with white-cedar reproduc-tion. Further, hardwoods (and tamarack) are deciduous and thus provide no winter shelter for deer.

Undesirable trees should be felled if they are merchantable or will provide deer browse; otherwise

they can be controlled by girdling or applying herbicide. Of course, to be effective, browse species must be felled in winter near deer concentrations. Felling or girdling of most or all undesirable trees in a stand should substantially reduce their reproduction by natural seeding, except for aspen and balsam poplar. Wind carries seed of these species long distances, so adequate control of their natural seeding by felling or girdling is probably impractical. However, if the canopy is not opened much, felling or girdling can practically eliminate vegetative reproduction of aspen, balsam poplar, and paper birch because they are intolerant.

Use of herbicide is another way to control vegetative reproduction of hardwoods, especially the more tolerant species such as black ash and red maple. To minimize suckering and sprouting, herbicide should be applied to a frill girdle around the base of uncut trees immediately after full leaf development. An effective herbicide is a low volatile ester of 2,4,5-T at 8 pounds acid equivalent (ae) per 100 gallons of No. 2 fuel oil solution, or the amine salt of 2,4-D or 2,4,5-T at 1 milliliter of a 50-percent water solution per inch of tree diameter. Uncut trees can be killed without girdling by basal spraying with Tordon 155[7] (a combination of picloram and 2,4,5-T) at 10 pounds ae per 100 gallons of fuel oil solution. Fresh hardwood stumps can be wet thoroughly with Tordon 101 (a combination of picloram and 2,4-D) at 5 pounds ae per 100 gallons of water solution to control suckering and sprouting.

Controlling Establishment

Reproduction Cutting

Present knowledge indicates that clearcutting, or felling of *all* trees, is the best way to obtain even-aged stands of northern white-cedar for timber and deeryards. However, unless suitable residual stems are expected (see p. 7), clearcutting must be done in narrow strips (or small patches) because reproduction depends on natural seeding, which has an effective range of only 2 or 3 chains. It may be possible to reproduce white-cedar on large clearcut patches by direct seeding, but this cannot be recommended until current research is completed.

Alternate clearcut strips have been widely used in the white-cedar type in the Lake States, but in most cases the uncut strips remain (fig. 2). These strips may receive inadequate natural seeding if they are clearcut. Therefore, until a better system is developed, a combination of clearcut and shelterwood strips is recommended for harvesting mature stands and reproducing new ones.

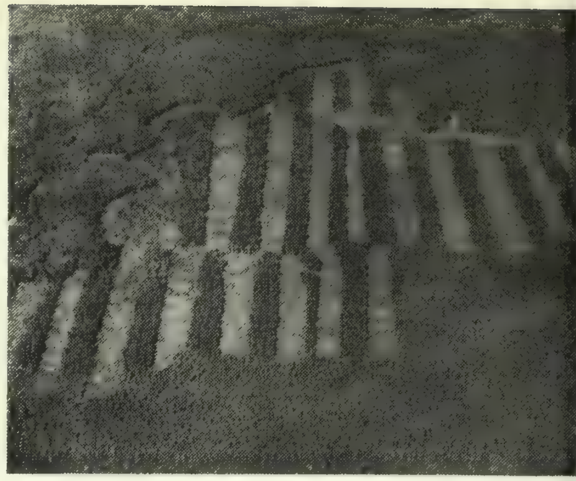

Figure 2. – *Typical large patch with alternate clear[cut] strips in the northern white-cedar type. Uncut str[ips] must be removed in 10 years or less to minim[ize] overbrowsing of reproduction by deer on the [cut] strips.*

This combination can be applied either as alternate[...] progressive strips. If alternate strips are used, one [...] should be clearcut and the other set cut in two sta[ges] (shelterwood). If progressive strips are used, sets of th[ree] are suggested – the first two being clearcut and the th[ird] one cut in two stages. The first stage or seed cutting [of] the shelterwood should leave a basal area of 60 squ[are] feet per acre in uniformly spaced dominant and [co]dominant trees of the most desirable species. These tr[ees] should be selected for good seed production, windfi[rm]ness, and timber quality.

Strip orientation has had little study, so str[...] recommendations cannot be made. Strips that [...] perpendicular to, and progress toward, the prevail[ing] wind direction should maximize seed dispersal [...] minimize wind damage. Some information suggests t[...] a northerly exposure is the most favorable for reprod[uc]ing white-cedar and associated conifers. East-west str[ips] with subsequent ones progressing southward, wo[uld] maximize this exposure. However, since the prevail[ing] wind direction in the Lake States is generally from [the] western quadrant (NW-SW), the manager will often h[ave] to compromise in deciding which way to orient str[ips]. The shape and orientation of a stand, especially if sm[all], are other important factors to consider in laying [out] strips.

Reliable information is also lacking to make str[...] recommendations on strip width. Clearcut strips sho[uld] generally vary from 1 chain wide where seed-bear[...]

[7] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

rees are short (less than 35 feet) to 2 chains wide where hese trees are tall (more than 60 feet). Strips can robably be 1 chain wider and receive adequate seed if hey have a mature stand of white-cedar on *both* sides. ince clearcutting is preferred to shelterwood for reproucing white-cedar, shelterwood strips should be only 1 r 2 chains wide to minimize the area they occupy.

The usual reproduction period between removing djacent clearcut strips, and between seed cutting and nal cutting in shelterwood strips, has been about 10 ears. However, this period should be shortened or ngthened as needed, depending on results from reprouction surveys (see p. 8). A new even-aged stand can e obtained in less than 10 years or up to 20 years using lternate or progressive strips, respectively. If timber onsiderations or the risk of overbrowsing call for arvesting or reproducing a stand as rapidly as possible, o seed cutting in the shelterwood strips and remove the lternate or the second set of clearcut strips at the same me. Residual shelterwood trees should adequately seed hese clearcut strips, thus substantially shortening the verall reproduction period.

Ways to make new harvest areas look better are iscussed under "Esthetics" (p. 11).

esidual Stems

These are trees of any size down to 6 inches tall that re expected to or do survive clearcutting. They may be f any species or age, and of seedling or vegetative rigin. Residual stems are "scarce" if they or their eproduction, especially by vegetative means, will not ecome dense enough to severely suppress reproduction f northern white-cedar or its valuable associate, black pruce. As mentioned under "Preparatory Treatment" p. 5), it is important to consider the reproductive otential of associated trees, particularly hardwoods.

Residual stems should be relied on to reproduce a and only if relatively young and healthy white-cedar ems are or will be predominant (at least 50 percent of asal area). Such stems are arbitrarily defined as being ss than 50 years old and having well-developed crowns. contrast, many of the white-cedar stems remaining ter clearcutting are 50 or more years old or have oorly developed crowns (for example, from browsing). ld stems also tend to be of layer origin, which often sults in poor form. Some old or unhealthy trees may ow satisfactorily after clearcutting and yield much er browse, but young seedlings are preferred for oducing timber and deer shelter. Therefore, residual stems should be saved to reproduce a stand only if: (1) 60 percent or more of the milacres[8] in the clearcut area will contain at least one young and healthy white-cedar *after* harvesting and (2) the cost of saving such stems does not exceed the cost of obtaining new white-cedar reproduction of equal density *and* size. Obviously, the stand must be harvested carefully and slash removed where it covers needed stems.

Residual stems of associated trees should be controlled enough that they or their reproduction will not severely suppress suitable residual stems (or new seedlings) *of white-cedar.* Undesirable trees should usually be felled if they will provide deer browse, otherwise they can be girdled. However, hardwoods should be treated with herbicide where experience indicates they will be a problem. Aerial spraying is recommended where residual hardwoods, especially of seedling or sapling size, are abundant (see p. 4); otherwise trees and stumps should be treated individually (see p. 6). Broadcast burning of slash is an efficient way to kill residual conifers, especially where many are of seedling or sapling size (see p. 15). Burning will kill back hardwoods, but herbicide is more effective on those that reproduce mainly from suckers or sprouts.

Slash Cover

This is "heavy" when slash hinders satisfactory reproduction by burying suitable residual stems or seedbeds (fig. 3, left). A heavy cover of slash is definitely detrimental, but a light cover is more favorable than practically none. Therefore, slash disposal is usually not needed in poorly stocked stands when the slash is spread evenly. Slash cover is also heavy when it creates an important fire hazard. However, the risk of fire is low on most white-cedar areas because they do not dry up much and there is little contact with human activities.

Broadcast burning is the preferred method of slash disposal except, of course, where shelterwood trees are present or residual stems are to be saved. Burning eliminates most slash, completely kills residual conifers, kills back hardwoods and brush, and probably improves seedbed conditions (fig. 3, center). However, because white-cedar has a short seeding range and space is needed for a slash-free alley around the perimeter of the strip, broadcast burning should be limited to strips 3 chains wide. (See Appendix, p. 15 for burning techniques.)

Full-tree skidding *in winter* is recommended for slash disposal on strips less than 3 chains wide. Stands

[8] *A milacre is 1/1,000 acre, usually 6.6 feet square.*

Figure 3. — *Typical clearcut areas where slash of northern white-cedar (browsed) and associated conifers was: not disposed of, leaving a "heavy" cover (left); broadcast burned (center); and removed by full-tree skidding (right).*

harvested by full-tree skidding, with branches and tops intact, apparently leave only a light cover of slash when felling and skidding are done with reasonable care (fig. 3, right). All trees should be felled as the harvesting progresses, leaving stumps as low as possible to minimize obstacles that would break off branches and tops during skidding. Also, the trees should be felled into the open rather than into the stand where more breakage would occur. If deer are in the vicinity, skidding of white-cedar and other browse species should be delayed a few days until the browse is eaten.

The overall cost of slash disposal should be less by full-tree skidding than by broadcast burning if most trees are merchantable. This is because skidding of full, merchantable trees by skilled loggers should require little or no extra compensation, whereas burning in strips only 3 chains wide usually has a relatively high cost per acre.

Natural Seeding

Northern white-cedar is a dependable seed producer. It bears good seed crops every 3 to 5 years, with light to medium crops in the intervening years. Adequate seed production starts at about 30 years but is best after 75 years on most sites. Seed dispersal usually starts in September and is fairly complete by November. Practically all of the seed is dispersed by wind. Since white-cedar is usually only 40 to 50 feet tall, the effective seeding range is estimated to be from 2 to chains.

Natural seeding of northern white-cedar, especially on burned organic soil, can result in new stands that are too dense for optimum timber growth or deeryards. To minimize this problem, the manager should survey the reproduction about 4 years after site preparation and if milacre stocking of white-cedar is 60 percent or more, the next set of uncut strips should be removed to eliminate further seeding on the cut strips. Of course, severe browsing and suppression of white-cedar reproduction must be prevented or white-cedar will not become established successfully.

Many of the common tree associates of northern white-cedar reproduce on clearcut areas, especially on slash-burned seedbeds, and some reproduce under the shelterwood. Black spruce and tamarack reproduce well after broadcast burning on organic soil sites if seed-bearing trees are within 3 or 4 chains. Although they may be outnumbered by white-cedar, spruce and tamarack grow faster and so will probably be important components of the new stand. To control natural seeding of black spruce and particularly tamarack, most seed-bearing trees should be harvested or otherwise killed during preparatory treatment (see p. 5). Seeding from spruce and tamarack could also be avoided by clearcutting large patches whose interiors are beyond the seeding range of

ese trees. However, this method of controlling compo-ion cannot be recommended until studies under way finitely show that such areas can be successfully produced to white-cedar by direct seeding.

Quaking aspen and paper birch not only reproduce ell on slash-burned seedbeds on organic soil sites, but o fairly well on unburned seedbeds such as those sulting from full-tree skidding. These trees have much eater seeding ranges than black spruce and tamarack, it is probably impractical to substantially reduce their tural seeding. Fortunately, aspen and birch are not pected to severely suppress northern white-cedar cept on the best sites. Here herbicide spraying may be sirable to release white-cedar as prescribed and dis-ssed under "Intermediate Treatment" (p. 4).

Controlling Damaging Agents

nd

reakage and uprooting of trees by wind can be portant causes of mortality in older stands of the thern white-cedar type, but the loss has sometimes n overrated. The risk of wind damage is greatest in nanaged mature stands of mixed composition. For mple, balsam fir and black spruce are more suscep-e to breakage or uprooting than white-cedar because y are usually taller and balsam fir commonly has butt , especially on the drier sites. Both breakage and ooting occur mainly along stand edges exposed to the vailing wind and in stands opened up by partial ting. By using the rotations and cutting methods ommended in this handbook, wind-caused mortality uld be minimal.

er and Hare

hite-tailed deer and snowshoe hare commonly wse northern white-cedar so severely that a stand not become established successfully after repro-tion cutting. However, as long as white-cedar stands be established or maintained, browsing is usually sidered beneficial to deer and hare – rather than aging to the reproduction – because it provides h nutritious food.

he reproduction cutting system recommended earlier 6) should minimize overbrowsing of young white-r if large patches (40 acres or more) of mature forest are completely cleared in 10 years or less. This is because: (1) deer and hare tend to avoid large openings, due to the lack of protective cover; (2) openings have deeper snow, which can deter deer in many parts of the northern Lake States; and (3) a great amount of browse is present in large young stands. Further information on how to minimize overbrowsing of white-cedar is discussed under "Deeryards" (p. 10).

Impeded Drainage

Poorly constructed or maintained roads have killed or reduced the growth of northern white-cedar and associated trees on thousands of acres of organic soil in the Lake States by impeding the normal movement of water. Beaver damming of natural watercourses or man-made drainage ditches has similar effects. Also, pipelines carrying natural gas and petroleum will cause damage unless cross drainage is provided.

Road-caused damage can be minimized by constructing and maintaining adequate collector and discharge ditches, and by using large culverts that are correctly positioned and maintained. Removal of beaver dams and judicious control of beaver can avert damage to valuable timber, deeryards, and the unsightliness of dying trees. Pipelines should have cross ditches about every 150 feet or less. These ditches can be through the backfill for pipe buried below ground or beneath pipe placed on the surface.

Other Agents

Wildfire easily kills northern white-cedar trees but good fire protection now results in little loss. During very dry periods fires can burn deeply in organic soil and become extremely difficult to put out. Biological agents other than deer and hare also cause damage to white-cedar. Unfortunately, their damage is often not recognized until the trees are cut, or if the damage is recognized, little is known about controlling it. Carpenter ants, both black and red, are the main insect enemies of white-cedar. They frequently attack partially decayed heartwood in living trees. Butt-rot fungi that cause a white stringy rot or a brown cubical rot are common in mature trees on the drier lowland sites. Woodpecker holes are the most common indicator that butt rot is present. Porcupines sometimes cause damage by girdling the stem, and red squirrels frequently eat flower buds and clip cone-bearing branches.

OTHER RESOURCE CONSIDERATIONS

Deeryards

Deeryard management in the northern white-cedar type is affected by the interaction of several factors such as yard size and condition, deer density, winter severity, and availability of browse in and around the yard. These factors vary substantially in different parts of the Lake States and are often difficult or impossible to control. Further, considerable knowledge on managing deeryards in the white-cedar type is based on experience rather than research, because the latter has been done mainly in areas with large yards and deep snow in upper Michigan. So, for these reasons, the present recommendations tend to be general and often cannot be applied directly to the various yarding situations found in the white-cedar type. This means that to obtain desired results the manager must use good judgment and modify the recommendations to fit local conditions.

Whenever possible, deeryard management should be concentrated on areas that have: (1) special importance as traditional or potential yards, (2) deer densities that do not exceed the carrying capacity, (3) a site index of 30 (medium) or higher for northern white-cedar, and (4) enough timber for commercial cutting.

In large deeryards (200 acres or more), the long-range objective should be to organize compartments that contain five age classes each, with 15 to 20 years between classes, in patches of 40 to 160 acres. The size and distribution of these patches should be planned carefully so that adequate deer shelter and browse will always be available on separate patches within each compartment (fig. 4). Cutting of any kind should be done in as many compartments as possible to distribute the deer herd more and to rehabilitate vital yards faster. Of course, northern white-cedar and hardwoods should be cut only during winter to provide deer with browse. Annual cutting is necessary to adequately feed deer where deep snow normally keeps them yarded most of the winter. Such cutting is also desirable where deer can move about more because it tends to attract them away from patches of young white-cedar, which is vulnerable to overbrowsing.

The main objective in small, isolated yards (less than 200 acres) should be to obtain and maintain a closed evergreen canopy for optimum deer shelter. Specific practices for achieving this objective are prescribed and discussed under "Intermediate Treatment" (p. 4).

Figure 4. — *This deer is browsing northern white-cea slash near the edge of a clearcut patch. The den stand in the background provides excellent shelter.*

Browse is usually scarce in small yards, so removal hardwoods or northern white-cedar should be done o by cutting during severe winters. This means m browse will have to come from young stands and win cutting of other forest types in the surrounding area.

In areas where small yards are vital for deer shelter, t rotation can be extended well beyond the longest o shown on page 3 because northern white-cedar is lo lived. Eventually, however, these yards will need to rehabilitated. Since they are probably too small handle the series of age classes recommended for la yards, the whole yard should be reproduced as a sin even-aged stand by strip cutting (see p. 6). The ti when a small yard is cut should be planned carefully that, if possible, adequate deer shelter will be availa elsewhere in the vicinity.

Other Wildlife Habitat

The white-cedar type is utilized to some extent many wildlife species besides white-tailed deer, a few which are mentioned elsewhere in this handbook. N openings and young stands certainly produce differe or more abundant wildlife food than mature whi cedar stands. For example, young stands should supp substantial populations of snowshoe hare and th accompanying predators as soon as the tree crowns be to close. Therefore, shrubs and hardwoods should not killed back with herbicide spraying unless the growth proportion of white-cedar reproduction definitely nee

o be increased (see p. 4). And even then, all stems hould not be killed because a mixture of shrubs and ardwoods with white-cedar and other conifers probably nhances wildlife habitat in general.

Some trout streams have their source in areas occupied y the northern white-cedar type or they pass through ıch areas. So, to keep the water cool, areas cleared for ew stands should probably: (1) have an uncut border etween them and the streams, (2) not exceed 40 acres ach, and (3) total only a small proportion of the ırrounding watershed.

Water

Current research findings indicate that clearcutting ›wland conifers in strips or large patches, or broadcast ırning the slash changes the quantity of water little. owever, if a stream flows from or through a clearcut ea, the water will have a higher concentration of ertain nutrients for a few years with or without ırning. Whether or not this increase in nutrients will ave an important effect downstream, especially in kes, is still unknown.

Esthetics

The manager can minimize the impact of harvesting on e esthetic appeal (fig. 5) of the northern white-cedar pe by: (1) having harvest boundaries follow natural e or forest type lines and (2) removing heavy slash ver and otherwise leaving harvest areas neat. Slash can removed by full-tree skidding and burned at the nding, or broadcast burned in the case of wide clearcut strips (see p. 7). Of course, as mentioned earlier, skidding of browse species should be delayed a few days if deer are in the vicinity.

Figure 5. – *The unusual bark and foliage patterns of northern white-cedar are esthetically appealing to many forest users, including hikers, snowshoers, and ski tourers.*

APPENDIX

Yield

Usable information on yield of northern white-cedar is limited and that on growth is practically nonexistent. Yield in a few common units or products can be determined for any fully stocked (normal), even-aged stand given its site index and age (tables 1 and 2). Site index is obtained from the average age (total) and average height (total) of dominant and codominant trees (fig. 6).

Volumetric yield can be estimated for a stand with less than full stocking because volume is proportional to basal area. Therefore, volumes in table 1 should be reduced by the percentage that the stand's basal area is less than the basal area in table 1.

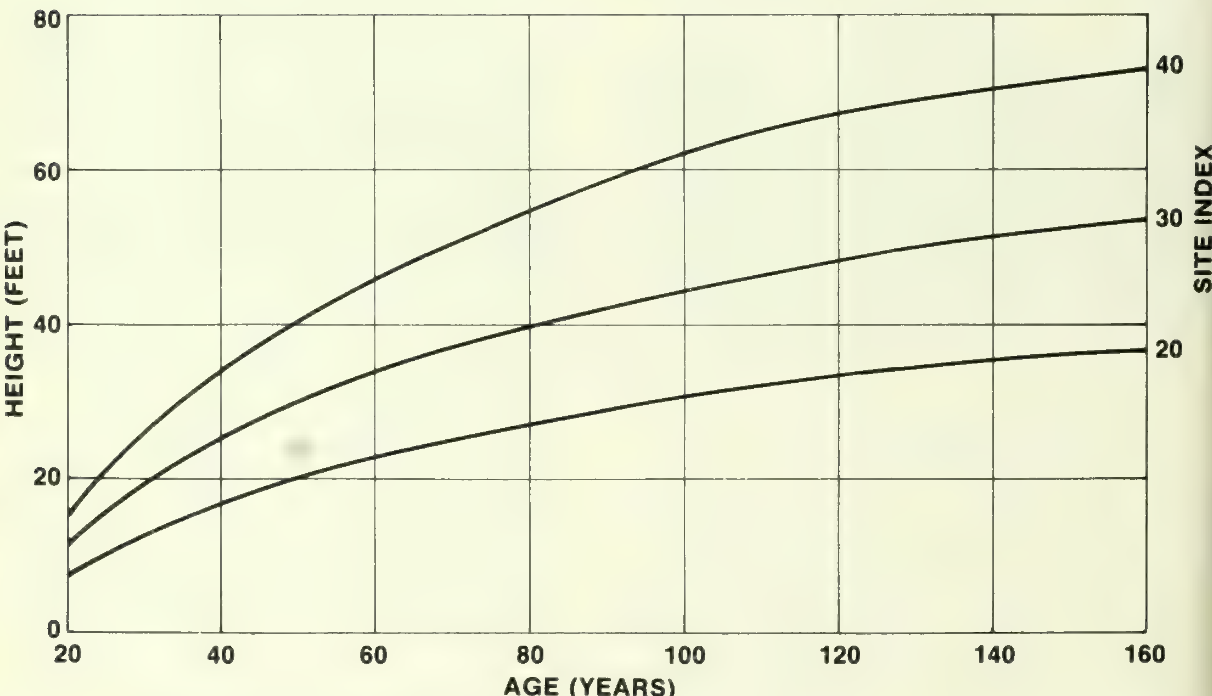

Figure 6. – *Site index curves for northern white-cedar stands. Adapted from Gevorkiantz and Duerr, 1939, "Volume and yield of northern white cedar in the Lake States", unpublished report on file at North Central Forest Experiment Station, St. Paul, Minn.*

Table 1. – *Yield per acre of fully stocked, even-aged stands of northern white-cedar by site index and age*[1]

Age	Height of dominants and co-dominants	Trees 0.1 inch d.b.h. and larger: Average d.b.h.	Number	Basal area	Total volume	Merchantable volume		
Years	*Feet*	*Inches*		*Square feet*	*Cubic feet*[2]	*Cubic feet*[3]	*Cords*[4]	*Board feet*[5]
				SITE INDEX 40				
60	47	6.2	850	180	3,490	2,460	31	2,840
80	56	8.7	470	195	4,200	3,540	45	9,540
100	64	10.7	320	200	4,700	4,180	53	15,600
120	69	12.4	250	205	5,040	4,560	58	19,900
140	72	13.6	210	210	5,270	4,800	61	22,790
160	75	14.5	180	215	5,420	4,950	63	24,410
				SITE INDEX 30				
60	35	4.5	1,550	170	2,600	1,440	18	230
80	41	6.2	860	180	3,240	2,480	31	2,460
100	46	7.7	580	190	3,670	3,100	39	6,000
120	50	8.9	450	195	3,960	3,480	44	9,220
140	53	9.8	380	200	4,160	3,720	47	11,570
160	55	10.4	340	200	4,280	3,860	49	13,000
				SITE INDEX 20				
60	22	3.0	3,120	155	1,690	280	4	--
80	26	4.2	1,740	170	2,180	1,120	14	120
100	29	5.2	1,180	175	2,500	1,700	22	740
120	32	6.0	930	180	2,720	2,050	26	1,680
140	34	6.5	790	185	2,860	2,280	29	2,590
160	35	6.9	720	185	2,960	2,410	30	3,220

[1]Values (except cords) adapted from Gevorkiantz and Duerr (1939) "Volume and yield of northern white-cedar in the Lake States", unpublished report on file at the North Central Forest Experiment Station, St. Paul, Minn. Values in the original report were for site indexes 41, 31, and 19; 40, 30, and 20 are shown here for convenience because the respective values are practically the same.

[2]Gross peeled volume of entire stem.

[3]Gross peeled volume between stump (height equal to d.b.h., in inches) and fixed top d.i.b. of 4 inches for trees 5.0 inches d.b.h. and larger.

[4]Gross rough volume obtained by dividing merchantable cubic-foot volume by 79, the assumed number of cubic feet of wood (inside bark) per cord.

[5]Volume (Scribner) between stump (height equal to d.b.h., in inches) and fixed top d.i.b. of 6 inches for trees 9.0 inches d.b.h. and larger.

Table 2. – *Poles and additional 7-foot posts in trees 4.0 inches d.b.h. and larger for fully stocked, even-aged stands of northern white-cedar by site index and age*[1]

Age (years)	Number of poles per acre, by length (feet): All	16	20	25	30	35	40	45	50	Number of posts per acre
SITE INDEX 40										
60	530	270	40	150	70	--	--	--	--	280
80	415	80	30	120	170	15	--	--	--	335
100	310	10	20	65	160	40	15	--	--	380
120	250	--	10	30	50	65	55	40	--	310
140	210	--	5	15	30	50	50	55	5	290
160	180	--	--	10	20	35	45	60	10	265
SITE INDEX 30										
60	105	--	95	10	--	--	--	--	--	1,205
80	530	270	170	80	10	--	--	--	--	155
100	465	145	115	165	35	5	--	--	--	285
120	405	85	10	235	60	15	--	--	--	250
140	360	55	--	200	70	30	5	--	--	250
160	325	40	--	165	75	35	10	--	--	200
SITE INDEX 20										
60	5	5	--	--	--	--	--	--	--	650
80	75	75	--	--	--	--	--	--	--	885
100	180	70	80	30	--	--	--	--	--	735
120	245	5	180	60	--	--	--	--	--	630
140	275	--	190	85	--	--	--	--	--	525
160	280	--	190	90	--	--	--	--	--	530

[1]Values adapted from Gevorkiantz and Duerr, 1939, "Volume and yield of northern white cedar in the Lake States", unpublished report on file at the North Central Forest Experiment Station, St. Paul, Minnesota. Values in the original report were for site indexes 41, 31, and 19; 40, 30, and 20 are shown here for convenience because the respective values are practically the same.

Broadcast Burning Techniques

nitial research and experience in upper Michigan and ated work in northern Minnesota indicate that rthern white-cedar slash, whether pure or mixed with sh of associated conifers, can be broadcast burned ely and effectively on organic soil sites. So burning on h sites should be successful throughout the Lake tes after resource managers gain some local experi-e.

burning is planned (see "Key," p. 2, 3), strips 3 ins wide must be located and harvested in such a way t they can be burned safely and efficiently. The main uirements for setting up and conducting a successful adcast burn on a clearcut strip are:

. Locate strip on *undrained* organic soil to avoid p ground fires that are difficult and expensive to put . Unless burning is essential for site preparation, slash uld be removed by full-tree skidding near drained anic soil, such as along ditches, and near upland sites. ning near drained organic soil should be done only r the surface soil has been wet down thoroughly. A eral soil firebreak should be constructed near upland s.

Make edges of strip smooth and reasonably straight void control problems resulting from sharp angles.

Cut all unmerchantable trees in the strip.

Plan cutting and skidding so as to distribute the h evenly, thus ensuring that the fire will spread over entire strip.

Leave a slash-free alley about 1/2 chain wide ind the perimeter of the strip.

Burn slash the first or second year after harvesting.

7. Burn when conditions will ensure consumption of most slash less than 1 inch in diameter (see below).

8. Burn when the wind direction is parallel to the strip to avoid serious crown scorch or mortality. If this direction is uncommon, then use center firing when the wind speed is only 0 to 5 miles per hour.

Burning on organic soil sites will probably be most successful in July and August of the first year or in May of the second year. Research and experience indicate that burning severe enough to kill back residual hardwoods and shrubs or to improve moss seedbeds requires drier and hotter conditions than burning to just consume slash or kill residual conifers. Most burning has been done under the following conditions:

Time or weather variable	**Burns in general**	**Severe burns**
Time since rain $\geq$ 0.1 inch	3 to 10 days	$\geq$7 days
Minimum relative humidity	30 to 60 percent	<45 percent
Maximum air temperature	60° to 90° F	$\geq$80° F
Maximum wind speed	5 to 15 mph	5 to 15 mph

On mineral soil sites, broadcast burning should probably be severe enough to expose mineral soil if natural seeding is planned. However, local conditions and experience may indicate that mechanical ground preparation such as scarification is more efficient than burning.

Metric Conversion Factors

To convert	*to*	*Multiply by*
Acres	Hectares	0.405
Board feet[1]	Cubic meters	0.005
Board feet/acre[1]	Cubic meters/hectare	0.012
Chains	Meters	20.117
Cords[1]	Cubic meters	2.605
Cords/acre[1]	Cubic meters/hectare	6.437
Cubic feet	Cubic meters	0.028
Cubic feet/acre	Cubic meters/hectare	0.070
Degrees Fahrenheit	Degrees Celsius	[2]
Feet	Meters	0.305
Gallons	Liters	3.785
Gallons/acre	Liters/hectare	9.353
Inches	Centimeters	2.540
Miles	Kilometers	1.609
Miles/hour	Meters/second	0.447
Number/acre	Number/hectare	2.471
Ounces	Grams	28.350
Ounces/acre	Grams/hectare	70.053
Pounds	Kilograms	0.454
Pounds/acre	Kilograms/hectare	1.121
Pounds/gallon	Kilograms/liter	0.120
Square feet	Square meters	0.093
Square feet/acre	Square meters/hectare	0.230
Tons	Metric tons	0.907
Tons/acre	Metric tons/hectare	2.242

[1]The conversion of board feet and cords to cubic meters can only be approximate; the factors are based on an assumed 5.663 board feet (log scale) per cubic foot and a cord with 92 cubic feet of solid material.

[2]To convert °F to °C, use the formula 5/9 (°F-32) or $\frac{°F-32}{1.8}$.

Common and Scientific Names of Plants and Animals

Common name	*Scientific name*
Plants	
Alder, speckled	*Alnus rugosa*
Ash, black	*Fraxinus nigra*
Aspen:	
Bigtooth	*Populus grandidentata*
Quaking	*Populus tremuloides*
Birch, paper	*Betula papyrifera*
Fir, balsam	*Abies balsamea*
Fungus, butt-rot:	
White stringy	*Poria subacida*
Brown cubical	Main species are: *Polyporus balsameus*, *Polyporus schweinitzii*
Maple, red	*Acer rubrum*
Moss, sphagnum	*Sphagnum* spp.
Poplar, balsam	*Populus balsamifera*
Spruce, black	*Picea mariana*
Tamarack	*Larix laricina*
White-cedar, northern	*Thuja occidentalis*
Willow	*Salix* spp.
Animals	
Ant, carpenter:	
Black	*Camponotus pennsylvanicus*
Red	*Camponotus ferrugineus*
Beaver	*Castor canadensis*
Deer, white-tailed	*Odocoileus virginianus*
Hare, snowshoe	*Lepus americanus*
Porcupine	*Erethizon dorsatum*
Squirrel, red	*Tamiasciurus hudsonicus*

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key – out of the reach of children and animals – and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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Nature is beautiful...leave only your footprints.

manager's handbook for

ASPEN IN THE NORTH CENTRAL STATES

E ERAL TECHNICAL REPORT NC-36

ORTH CENTRAL FOREST EXPERIMENT STATION FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

Other Manager's Handbooks are:

- Jack pine – GTR-NC-32
- Red pine – GTR-NC-33
- Black spruce – GTR-NC-34
- Northern white-cedar – GTR-NC-35
- Oaks – GTR-NC-37
- Black walnut – GTR-NC-38
- Northern hardwoods – GTR-NC-39

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1977

FOREWORD

This is one of a series of manager's handbooks for the important forest types of the north central States. The purpose of this series is to present the land manager with the latest and best information available on handling these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. However, ways to modify management practice to maintain or enhance other values are included if sound information is available.

The author has, in certain instances, drawn freely on unpublished information provided by scientists and managers outside his specialty. He is also grateful to the several technical reviewers throughout the region who made many helpful comments.

The handbooks have a similar format, highlighted by a "Key to Recommendations". Here the manager can find in logical sequence the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbooks. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objective. The manager must also apply new research findings as they become available so that the culture of these important forest types can be continually improved.

CONTENTS

ASPEN IN THE NORTH-CENTRAL STATES

Donald A. Perala, *Silviculturist*
Grand Rapids, Minnesota

SILVICAL HIGHLIGHTS

The bulk of the aspen[1] in the north central States is in Minnesota, Wisconsin, and Michigan where 13 million acres (one-fourth of the commercial forest land) of aspen type contain 80 percent of the aspen growing stock; the rest of the growing stock is in conifer types (7 percent) and other hardwood types (13 percent). Quaking and bigtooth aspens occur on nearly every soil type but grow best on deep, well drained soils.

Aspens are highly sensitive to shade, soil compaction, fire and mechanical injury to the root system. The species grows rapidly, thins itself naturally from competition, insects, and diseases, and matures in 30 to 70 years; occasional trees will survive 100 years or more. Without disturbance, aspen stands will be replaced by more tolerant or longer-lived associates.

Aspen typically sprouts many thousands of suckers per acre from the shallow parent root system after a stand has been opened by fire, windthrow, or cutting. The suckers arising from the same tree are genetically identical to the parent and are called a "clone". Suckers of the same clone have uniform characteristics, but suckers of different clones can vary widely – especially in bigtooth aspen. Single clones typically cover 1/10 to 1/5 acre, occasionally up to 4 acres.

MANAGEMENT OBJECTIVES AND NEEDS

About one-third of the aspen-birch forest type in Minnesota, Wisconsin, and Michigan is growing much below potential. The management objectives considered in this handbook are to improve yields of timber, water, or wildlife in this forest type while minimizing impact on the landscape.

The recommended silvicultural system for growing and reproducing aspen is complete clearcutting at rotation age to regenerate pure, fully stocked stands of suckers. In young stands that were not established by complete clearcutting, the residual trees need to be removed as early as possible. One or two thinnings to control stand density are needed to greatly increase the yield and shorten rotations for saw logs and veneer, but thinning is not recommended for fiber production. The manager will need considerable skill and wisdom to balance the output of timber, water, and wildlife while maintaining a pleasing landscape.

KEY TO RECOMMENDATIONS

The following key recommends the management techniques that will improve the yields of timber and water, or increase wildlife for given stand and site conditions and objectives. Not every possible situation can be covered in detail, so the manager must choose the alternatives that come closest to describing his condi-

[1] *For scientific names of plants and animals, see Appendix, p. 27.*

tions. If growing aspen is not reasonable, alternate species are recommended.

The timber recommendations will have some effect on water, wildlife, and landscape values. These effects are discussed in the appropriate sections (p. 9-12) where modified or alternative practices are recommended.

Start with the first pair of like-numbered statemen Choose the statement that better describes your fore and find either a number, a partial recommendation ar number, or a final recommendation. If a number given, find that pair of statements and continue t process until a final recommendation is reached. T page numbers refer you to appropriate discussion in t "Management Considerations" section that follows.

1. Site index 60 or greater (p. 3) . . . . WELL SUITED FOR ASPEN TIMBER MANAGEMENT. .
1. Site index less than 60 (p. 3) . . . . POORLY SUITED FOR ASPEN TIMBER MANAGEMENT. .

  2. Aspen management is primary objective . . . .
  2. Aspen management is not primary objective . . . .

3. Stand is well stocked, either pure or mixed (p. 5) . . . .
3. Stand is understocked (p. 5) . . . .

  4. Fiber management option . . . . REGENERATE WHEN MATURE (p. 3
  4. Sawtimber or veneer management option, site index 70+ . . . .

5. Stand age 10 to 30 years . . . . THIN ACCORDING TO SCHEDULE (p
5. Stand age over 30 years . . . . REGENERATE WHEN MATURE (p

  6. Operable cut expected at rotation (p. 5) . . . . WAIT, REHABILITATE (p
  6. No possibility of operable cut (p. 5) . . . . REHABILITATE NOW (p

7. Stand is pure, well stocked (p. 5) . . . . HARVEST WHEN MERCHANTABLE, CONVERT TO CONIFERS (p
7. Stand is mixed or understocked . . . .

  8. Stand understocked (p. 5) . . . . CONVERT TO CONIFERS (p
  8. Stand mixed . . . .

9. Stand is spruce-fir mixed . . . . GROW ASPEN WITH CONIFERS (
9. Stand is other conifers or hardwoods mixed . . . . PROMOTE SUCCESSION (

  10. Timber management is objective . . . . CONVERT TO CONIFERS (
  10. Watershed or wildlife management is objective . . . .

11. General area is less than 25 percent aspen . . . . MAINTAIN ASPEN (
11. General area is more than 25 percent aspen . . . .

  12. Deer or moose management is objective . . . .
  12. Watershed or other wildlife management is objective . . . . MAINTAIN ASPEN (

13. General area is less than 15 percent conifers . . . . CONVERT TO CONIFERS (p. 5,
13. General area is more than 15 percent conifers . . . . MAINTAIN ASPEN (

TIMBER MANAGEMENT CONSIDERATIONS

Controlling Stand Establishment

The land manager must decide what species to grow and the end products for those species. These decisions will be influenced considerably by market conditions; the relative local abundance of aspen, hardwood, conifer types; the long-term availability of aspen other species; watershed, wildlife, and esthetic ob tives; and the productivity of forest soils for var species.

Estimating Site Productivity

ite Index Curves

Site index is commonly determined by comparing the ean total height and age of dominants and codomiınts with published site index curves. Site indices are pressed in even units of 10 feet at age 50, the class terval being 56 to 65 for site index 60, for example. se site index curves (see Appendix, fig. 12) to estimate e index for quaking aspen. Up to age 50 the estimates ll be reasonably accurate throughout most of the rth central area; after age 50 accuracy can drop nificantly because of local variation in height growth. e only curves for bigtooth aspen are from northern wer Michigan (see Appendix, fig. 13). When these rves are used elsewhere for bigtooth aspen, the site dex estimates are likely to be less accurate.

The genetic variation between clones can sometimes ise considerable error in aspen site index estimation e Appendix, fig. 14). To accurately estimate site dex where clonal growth differences are pronounced, asure two dominant aspens in each of three clones resentative of the stand. The average height of the ee clones along with tree age will give reliable site dex values. Sampling only the tallest clone or clones ıld overestimate site index by 5 to 10 percent.

il Examination

ite index curves are not reliable for stands less than years old, or in stands where growth was slowed ause of fire, or because partial cutting left dense rstories. To estimate site index in such stands, use and topographic features instead of heights (see pendix, tables 1 and 2). Soil surveys by the USDA l Conservation Service and other agencies can also be y useful (fig. 1).

ternative Species

nly site index 60 or better should be considered for en timber management although poorer sites can be naged for aspen for other purposes. Conifers are ally more productive than aspen on poorer sites so land manager may wish to convert to conifers. The l manager may also wish to convert better aspen sites other species. The following tabulation gives quaking en site index values and the corresponding site index some alternative species:

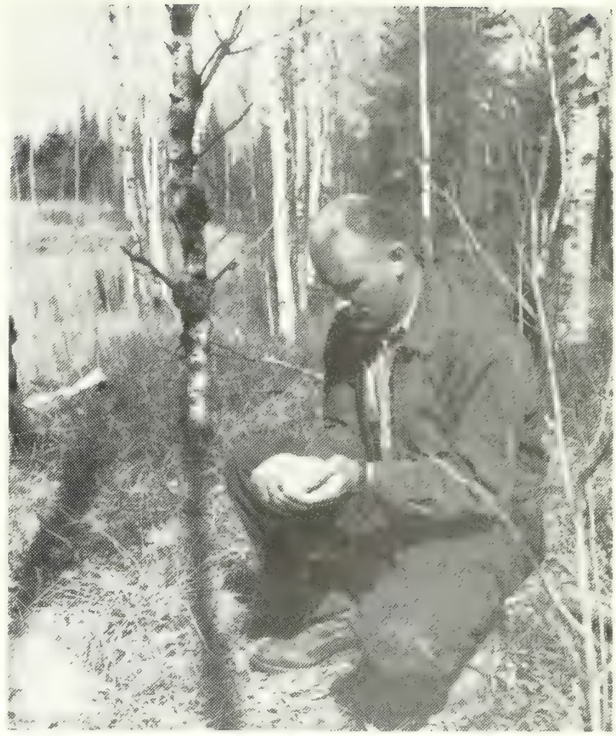

Figure 1. — *This aspen stand has a measured site index of 42. Since the stand originated after fire, the true site index of the stand is underestimated. A soil examination is needed to accurately assess the potential productivity of the site.*

If quaking aspen site index is:	Then site index for these species is: Red pine	Basswood	Paper Birch
40	46	44	40
50	50	50	47
60	54	56	55
70	59	62	62
80	63	68	70

Regenerating Aspen

Basic Requirements

For best aspen sucker regeneration: (1) the soil must be well drained and aerated, and (2) the parent stand must have a minimum aspen density of 50 trees or 20 square feet basal area per acre. To stimulate suckering, allow heat and light to reach the forest floor by removing as much of the overstory as possible, preferably all trees 2 inches or more in d.b.h. (as little as 10 to 15 square feet basal area of residual overstory will slow sucker growth by 35 to 40 percent) (fig. 2). In some cases the understory may also need to be controlled. Harvesting the overstory in summer helps in this regard.

Figure 2. – *One-year-old quaking aspen root sprouts (suckers).*

Site Preparation

Harvesting the old stand helps prepare the site for regenerating aspen, but some harvesting methods are better than others in this respect. Full-tree or tree-length harvesting scarifies and eliminates enough competing vegetation during felling and skidding that further site preparation is often unnecessary. On the other hand, traditional or "shortwood" harvesting must usually be followed by additional site preparation. Of course, stands that are not commercially harvestable must also be treated. Table 3 (Appendix) lists how effective in encouraging suckering various site preparation techniques are under certain overstory, understory, and forest floor conditions.

Options to encourage suckering include shearing, chainsaw felling, girdling, treating with herbicides, and prescribed burning. Discing and roller chipping are not recommended because their stimulation of suckering is often negated by damage they do to the parent roots (fig. 3).

Figure 3. – *Discing or roller chopping disturbs t parent root stock and reduces sucker growth a survival.*

Shearing is the most successful mechanical site prep ation method. A sharp blade and shearing on frozen sc will least disturb the parent root system and maxim sucker production.

Girdle or treat with herbicides[2] only in fully stock stands. (In poorly stocked stands every tree is needed increase suckering, so all should be sheared or chains felled instead.) Girdling or chemical treatment are m efficient on trees over 5 inches d.b.h. Girdles shou penetrate to the sapwood and encircle the stem co pletely. Diluted herbicides such as 2,4-D amine, 2,4,5 or picloram can be injected 1/4- to 1/2-inch into sapwood as close to the tree base as possible, or sprayed on the tree base in oil solution any time duri the snow-free season.

Aerial spraying during July 15 to August 15 with 3 l 2,4-D ae (acid equivalent) in 5 gallons of water mixtu per acre will control paper birch and aspen residual tre Substitute 2,4,5-T for 2,4-D if red oak is prese Although the aspens will be top-killed, they will respro the next year to provide a fully stocked stand. Harvest stands should be sprayed within 1 year.

---

[2] *See Pesticide Precautionary Statement, p. 28.*

Prescribed burning should be used only by personnel xperienced in fire behavior and fire weather. It is commended only when other site preparation methods e impractical or in poorly stocked, brushy, or sodded ands. Although burning increases suckering, it also nds to slow sucker growth. Harvested stands should be rned within 1 year; the best time is in the spring fore growth starts. If snow still lies in the surrounding nber, or if the surrounding timber is hardwood, the rn can be easily confined to the harvested area (see Prescribed Burning" and table 4 in Appendix).

ocking Standards

By age 2, when most suckering will have occurred, cker stands should exceed 85 percent milacre stocking, about 4,000 to 5,000 stems per acre (fig. 4). As ocking drops below 4,000 per acre at age 2, the ances that the stand will develop to an economically erable density decrease rapidly with small increases in ortality. The development of sucker stands should be ecked periodically (see "Forecasting Future Opera-ity" and fig. 15, Appendix).

Fure 4. – *Regeneration of dense sucker stands is the best guarantee of high aspen productivity.*

Controlling Composition

Cmpetition

an aspen stand is properly regenerated at maturity, it will outgrow other regenerating species; these then may develop as an understory. Overtopping trees left after harvest, however, strongly suppress aspen growth, and should be removed in initial site preparation or by cleanings and thinnings within 10 years.

Growing Conifers with Aspen

Only white spruce and balsam fir can easily be managed concurrently with aspen. In fact it is difficult to manage spruce and fir to the exclusion of aspen, and vice-versa, where they exist together. The total fiber yield may be greater in these mixed stands than if pure stands of any one species are grown (fig. 5).

Figure 5. – *Aspen and balsam fir can be grown together for landscape variety and forest crop diversity.*

Where mature aspen has an understory of immature spruce-fir, clearcut the aspen at age 30 to 50 to release the conifer understory. Openings in the conifer canopy will be large enough to allow good aspen sucker development in scattered patches. Manage the conifers either by group selection, shelterwood, or diameter limits according to age structure and the proportion of aspen. Make shelterwood and diameter limit cuttings to encourage advance spruce-fir regeneration when the aspen component is minor or scattered. Clearcut mature aspen and conifers to regenerate a fully stocked aspen sucker stand. If advance reproduction is sparse, clearcuts should be small (preferably less than 20 acres); large clearcuts should not exceed 200 feet in width and their

length should be oriented perpendicular to prevailing winds since conifer seeds must blow in from outside. Although spruce-fir regeneration will be minor the next 10 to 20 years, by the time aspen is mature again, understory conifers will be re-established and the cycle can be repeated indefinitely.

Promoting Succession

Pines or northern hardwoods often become established as an understory in aspen. Pines cannot be easily managed concurrently with aspen so the aspen can be removed carefully whenever operable. Aspen does not compete well with northern hardwoods and should be removed in partial cuts to recommended densities for northern hardwoods.

Expanding "Plus" Clones

Variation in some aspen stands is enormous; yield can differ as much as 200 percent between clones on the same site. Since much of this variation is genetic, an opportunity for stand improvement exists both during thinnings and during the regeneration cut.

During thinnings, favor the best ("plus") clones for crop trees. Be alert for obvious traits such as superior stem form and growth rate, lack of branchiness, and resistance to hypoxylon canker and heart rot (fig. 6). In mixed stands of bigtooth and quaking aspen on dry exposed sites, generally favor bigtooth because of its superior growth and greater resistance to diseases and insects. However, as soil moisture increases, quaking aspen often tends to perform better and should be favored.

Identify the boundary of plus clones and remove competing poor ("minus") clones during thinning. Do not, however, open the stand excessively, but maintain full stocking by leaving minus trees where necessary (see Appendix, fig. 16). The suckers that arise from the minus clones will soon die from shading.

Suckering of minus clones can also be controlled during the regeneration cut. The fall or spring 2 years before harvest, favor plus clones resistant to heart rot (indicated by the absence of conks) by basally spraying competing minus clones. Or during felling (when susceptibility to decay is most obvious) spray the exposed cambium of cut stumps of competing minus clones. In both cases, use 2 gallons of Tordon 155[2,3] in 100

Figure 6. — *Well formed, disease-resistant clones on go sites are required in a thinning program to prod saw logs and veneer bolts.*

gallons of fuel oil and thoroughly wet the treated ar As an alternative, girdle minus clones in the summ years prior to harvest to reduce suckering. Do not d harvesting more than 2 years after girdling or chem treatment because a significant amount of wood deteriorate after the trees die.

Do not treat minus trees more than 50 feet beyo plus clone to assure full stocking with aspen suck Several rotations will probably be needed to rep most minus clones since plus clones can be extende only 20 to 40 feet each rotation, but the quality of stand will be steadily upgraded each rotation.

Improving Growth

The practices that control stand establishment composition will markedly affect stand growth. Gene ly, dense stands are initially more pest resistant and yield more fiber at maturity than more modera stocked stands. On the other hand, trees in dense sta do not grow in diameter as quickly as modera stocked stands and will yield less sawtimber and ven

[3]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

Yields can be increased by (1) thinning and (2) djusting rotation ages to maximize mean annual increment. Both options are recommended for growing awtimber and veneer; for fiber, only adjusting the otation age is recommended.

hinning

Only well-formed, disease-resistant clones on sites 70 nd better can yield significant amounts of sawtimber nd veneer. Generally, a single commercial thinning is ecommended (schedule A as follows). However, site ndex 80 or better stands will produce substantially ore sawtimber and veneer if precommercially thinned s well (schedule B). In schedule A, thin once at about ge 30 when basal area has surpassed 120 to 140 square et. Leave about 240 trees and 60 to 70 square feet per cre. In schedule B, the precommercial thinning should ave 550 trees per acre at about age 10 when the trees e still small enough to be easily felled by hand (fig. 7). hin a second time at about age 30 when basal area has rpassed 130 square feet per acre. Leave 200 trees and) to 90 square feet per acre. Delay the regeneration cut in either schedule as long as the stand is healthy and shows little sign of heart rot — age 50 to 60 in most cases.

Assuming a regeneration cut at age 55, schedules A and B in site index 80 aspen would average 12 to 14 inches d.b.h., compared to 9.5 inches without thinning. Thinning produces up to 140 percent more veneer and up to 40 percent more sawtimber than without thinning, with the greatest gains from the two-thinning schedule (see Appendix, fig. 17). Thinning can produce the same amount of sawtimber in 10 years less time, or the same amount of veneer in 14 years less time than without thinning.

The smaller trees and tops of crop trees could give these additional yields of whole chips:

Schedule	Commercial thinning	Regeneration cut	Rotation total
	— (fresh weight, tons per acre) —		
A	54 (4.3)[4]	63	117
B	41 (5.7)	65	106

[4] *Mean diameters in parentheses.*

Figure 7. — *The first thinning at about age 10 should leave 550 trees per acre.*

Thinnings need only remove other species competing in or above the aspen overstory, not those in the understory. Always remove poor risk aspen; never remove potential crop trees. Uniform spacing is not critical except that large openings (which can cause aspen sunscald) should be avoided. Because the material removed in thinnings is small diameter, we recommend chipping the whole tree to improve utilization.

Rotation Length

The regeneration cut should be timed to maximize mean annual increment of the products desired. (Economic rotations are usually 5 to 10 years shorter.) Generally, the larger the product, and the lower the site index, the longer will be the rotation. However, in some areas, low site index aspen deteriorates earlier than high site aspen and should be harvested first.

Rotation lengths for quaking and bigtooth aspen in the Lake States by product, site index class, and with and without thinning, are given in Appendix, table 5. Stands managed for sawtimber and veneer on rotations of 50 to 70 years must be chosen carefully and inspected often for signs of deterioration. Shorten the rotation if there will be significant loss and consider another product for the next rotation.

Damaging Agents and Control Measures

Diseases

A common disease in young aspen stands is "shepherd's crook", which usually only blackens and kills back the terminal. New growth recovers the following year and no control is feasible or necessary.

Hypoxylon canker commonly infects stands of all ages and is the only disease causing significant mortality over recommended fiber rotation lengths. About 3 percent of the Lake States aspen trees are killed annually by this infection (fig. 8). Bigtooth aspen is five times as resistant as quaking aspen. The only known control is to maintain full stocking throughout the rotation to assure at least partial replacement of growth loss. Cultural techniques to encourage the expansion of resistant clones or bigtooth aspen clones into quaking aspen clones would increase stand resistance to infection (see "Expanding 'Plus' Clones"). Where it is difficult to obtain full sucker stocking and the infection rate is high, conversion to other species is recommended (see "Stocking Standards").

Figure 8. — *Hypoxylon canker of aspen, the secon most important pathogen of aspen in the Lake Stat The scalpel is embedded in the central portion o canker.*

Heart rot decays the heartwood of stands neari maturity and is the main limitation to growing aspen veneer rotations exceeding 50 or 60 years (fig. 9). Los to this disease are not serious for shorter rotations. He rot probably enters bark wounds or dead branch stu In the first stage of decay the wood is still firm but la becomes discolored enough to cause degrade in lumb in the final stage the heart rot becomes soft, punky, a is often large enough to cull a log. If the decay is sm or firm, the log can be held in a turning chuck and rot veneer yield will be little affected. On the average, final (soft) stage of decay will reduce gross merchanta yields by 1, 2, 5, and 10 percent at ages 40, 50, 60, a 70, respectively. If all stages of decay are considered, 12, 16, and 20 percent defect, respectively, will found. Sporophores or "conks" indicate that the fi decay stage extends 2 to 5 feet above and below conk, depending on their number and size, but absence of conks does not necessarily mean the abse of decay.

Besides age, tree vigor and inherent resistance inf ence decay. Vigorous, fast growing trees are relativ resistant, although the relationship between decay site index is not consistent. Since certain clones considerably more decay resistant than others on same site, inherited resistance is probably more imp ant than site index. No controls are known for disease except to make the regeneration cut ea enough to avoid unacceptable losses.

gure 9. – *Conk of* Phellinus igniarius – *the main deterrent to growing aspen to old ages.*

sects

Once past the juvenile stage, aspen is seldom killed rectly by insects. However, insects such as the poplar rer may enhance mortality by weakening the tree or oviding infection courts for pathogens. A number of her wood borers can damage and kill young suckers. le-size and mature stands are more susceptible to foliating insects such as the forest tent caterpillar and e large aspen tortrix. Even repeated defoliation does t cause much direct mortality, except on sites with h water tables – the main effect is temporary loss in owth. No direct insect control is now practiced in pen although dense sucker stands should be regener- d to minimize borer damage.

re

spen stands are relatively low in flammability and s are easily controlled. However, even surface fires either kill or injure aspens and cause significant wth loss and early stand breakup. Fire should be luded from aspen stands except for regeneration and n then excessively hot fires should be avoided.

Weather

New spring growth can be killed by frost, but growth resumes and little permanent damage results. Aspen is prone to windthrow or breakage, particularly when weakened by boring insects or disease. Young sucker stands can be seriously damaged and sometimes killed back by hail.

Improperly Timed Silvicultural Practices

Soil compaction from heavy machines can reduce future aspen yields 5 to 10 percent by lowering soil aeration required for vigorous suckering. The potential for compaction is most severe on wet soils having a high clay content, and is minimal on dry sandy soils. Disperse skidding to minimize compaction during the summer by mechanized logging. Winter logging causes less soil compaction than summer logging, but does not disturb competing vegetation as much – a factor to consider on brushy aspen sites. Shearing for aspen regeneration should always be done when soils are frozen.

Conversion to Conifers

Aspen stands to be converted to conifers should first be harvested of all usable material. Prepare the site mechanically by shearing, roller chopping, or barrel scarifying, or treating chemically between July 15 and August 15 with picloram plus 2,4-D (0.5 pounds + 2 pounds per acre) in 10 to 20 gallons water per acre.[2] Plant suitable conifers the following spring.

Release conifers from aspen suckers as needed using 2,4-D or a 50 percent mixture with 2,4,5-T when oak or other hardwoods are present. Use total rates of 3 pounds per acre in 4 to 5 gallons water mixture for aerial spraying; 3 pounds per acre in 10 to 20 gallons for ground spraying. White spruce and red pine are safe to release after July 1 but release is best after July 15. Jack pine is not safe to release until August 1. Complete the release operations by August 15. Where chemicals cannot be used, hand release during the growing season (June, July, early August) to lessen regrowth of aspen.

OTHER RESOURCE CONSIDERATIONS

Water

spen forests can have considerable impact on water yi d, depending on how they are managed. Harvesting (e her intermediate thinnings or regeneration clearcuts) or a sustained yield forest will have little impact on water yield, quality, or timing, because only 1/30 to 1/60 of the total acreage is cut during any 1 year. However, an individual watershed that is completely clearcut may yield 3 to 4.5 inches more water the first few years after cutting. This yield diminishes with time; after 6 to 7 years the new stand will differ little in water

yield from mature aspen. Few nutrients are lost after clearcutting because of rapid vegetation growth. Sedimentation is insignificant; most sediment results from construction of roads and skid trails and can be avoided. Timing of peak flow from a clearcut watershed may be advanced by 4 days. Converting aspen to conifers has the most significant long-term effect on water yields. A pure aspen stand will yield 2.5 inches more water annually than a pure stand of red pine because it intercepts less precipitation. As long as conifers are maintained, water yields will remain lower than if the watershed were left in aspen.

Wildlife

Game Species

Ruffed grouse utilize aspen stands of all ages. Juvenile sucker stands at age 2 (12,000 to 14,000 stems per acre) up to about age 10 (6,000 to 8,000 per acre) are important brood habitats for grouse. Sapling and pole stands aged 10 to 25 are preferred overwintering and breeding cover. Aspen stands older than age 25 (when stem densities usually fall below 2,000 per acre) are devoid of breeding grouse but serve as nesting cover and as a very important food source. A primary year-round food of grouse is aspen leaves and buds, best provided by stands nearing maturity. The staminate (male) flower buds of aspen are the most important nutritive source for grouse. Some male clones preferred by grouse may be 30 percent richer in proteins than male clones that are not eaten. Finally, snow accumulates earlier and deeper in aspen stands than in conifer stands. This provides burrowing cover, which is very important during most winters.

To increase ruffed grouse, aspen should be clearcut on a 40- to 50-year rotation, in patches no larger than 10 acres in each 40 acres, and at 10-year intervals. M clones that grouse prefer should be favored duri intermediate thinnings and during regeneration cuts ("Expand Plus Clones"). Intermediate thinnings or sh rotations are not recommended for grouse manageme

White-tailed deer rely heavily on the aspen ty especially for spring and fall range, and for winter ra within 1/2-mile of winter cover types (fig. 10). Herba ous and shrubby growth associated with aspen is usua more abundant because the intolerant aspen adm more sunlight to the forest floor than do the m tolerant hardwoods and conifers. The quality a availability of herbaceous vegetation in the spring a fall greatly affect the vigor of northern deer her Conifer cover during winter to minimize body heat l is even more important. Pure aspen or hardwood sta offer poor insulation and protection from wind co pared to dense stands of lowland conifers (especia northern white-cedar), balsam fir, or pines.

Deer populations can be increased by limiting asp clearcuts to 40 acres (preferably 20 acres) and by sh rotation management (25 to 30 years on 5- to 10-y intervals) of aspen stands within 1/2 mile of winter d yards. (The cutting schedule recommended for gro could also be applied for deer, with somewhat redu benefits.) Ideal deer range should be 15 to 20 perc scattered conifer stands, and 5 to 10 percent sodded a brushy openings (which are important spring and feeding areas). Hardwood forest types should contain to 35 percent of their area in aspen stands, and percent of the aspen should be 1 to 10 years old.

Moose are dependent upon the aspen community provide a large amount of browse. For moose mana ment, clearcuts can be up to 100 acres; the st composition should be similar to that for deer.

Figure 10. – *Moose, white-tailed deer, and beaver are some of the wildlife species that depend on aspen for food and cover. (Deer and moose photos courtesy of Minnesota DNR.)*

maller Birds and Mammals

Beaver populations should be controlled so they will ot over-utilize riparian aspen forests by repeatedly opping sucker stands. Repeated cropping can result in ath of the stand and food scarcity for future popula-ons.

Cavity nesting birds and mammals can be encouraged leaving standing dead snags. These will not interfere th sucker regeneration of the new stand. Numerous ngbirds, such as the Nashville warbler, a variety of arrows, hermit thrush, and others, need all elements of od and cover – from herbaceous openings and early ges of forest succession (such as aspen) to stands of ature and old-growth timber.

are and Endangered Species

Three rare or endangered species using the aspen type the bald eagle, osprey, and eastern timber wolf. All protected by Federal and State laws. The following bulation lists restrictions on management activities for prey and eagle nest trees:

tance m nest	Osprey nests	Eagle nests
to 350 ft.	No activity anytime	No activity anytime
0 to 650 ft.	No activity March to July	Thinning and pruning OK (no clearcutting) October to mid-February; no activity rest of year
0 and beyond	Normal activities OK	–
0 ft. to mile	-	Normal activities October to mid-February only; no activities rest of year

f areas more than 1/4 mile away are visible from the le nest, the outer zone can be extended to 1/2 mile in t direction. Roads and trails within 1/4 mile of eagle ts should be closed where possible. Scattered old-wth trees, particularly the pines, should be reserved much as possible for future nest trees.

he timber wolf generally requires no special habitat nagement beyond good management for deer, moose, d beaver. These are the primary prey of wolves and bitat manipulation for them will serve the wolf as l.

Landscape

Aspen is dominant and highly visible in the landscape of northern forests. Because it is abundant and predominantly maintained through clearcutting, how it is managed will have important impacts upon the landscape and recreation experiences. Aspen landscape management is needed most in stands in the foreground of scenic areas, travel corridors, use areas, and water bodies frequented by and readily visible to large numbers of forest visitors. Important factors to be considered in avoiding unsightly management practices are *viewing distance, size, shape, edge, distribution or spacing, timing, vistas,* and *operations.*

The foreground (0 to 1/2 mile) and middleground (1/2 to 3 miles) landscape zones are most important because they are most readily seen. The background zone (3 miles +) is important when it is highly visible and provides a scenic backdrop.

Foreground landscapes can be enhanced by:

1. Providing vistas that expose and frame scenic features.
2. Utilizing clearcuts to create visual variety by opening up dense stands, and breaking up straight lines of timber with curved lines and irregular openings.
3. Leaving attractive trees and snags and those of special interest.
4. Providing diversity in plant species, age class, size, and type.
5. Using transition vegetation along edges.
6. Varying the sizes and shapes of cuts.
7. Converting to other vegetative types.

An aspen regeneration cut has less impact if its *size* does not dominate and if it is varied and in scale with natural or man-made openings that may occur in the landscape. The apparent size of a cut can be reduced by restricting the amount of cut area seen from any one viewing position. Factors such as distance, shape, and screening provided by intervening ridges or other landforms and islands or clumps of vegetation help to limit the apparent size of cuts.

Irregular, free-form *shapes* that follow natural projections, indentations, soils, and topographic features expose smaller areas of clearcut to view. Avoid cutting boundaries in long straight unnatural edges or in geometric shapes which clash with natural landscape forms.

Clearcut openings whose *edges* contrast sharply with the surrounding timber can be "feathered" to soften

such contrasts. Make use of existing openings as part of edge. Thin into adjacent stands to develop an irregular loose appearance and spacing. Develop a diversity of plants in species, size, and texture, to help soften edge (fig. 11).

Regularly spaced clearcuts of nearly the same size and shape are seldom visually pleasing. *Dispersal* and *irregular spacing* should be used to avoid a repetitious pattern.

Aspen harvests should be scheduled so that sufficient *time* elapses before new areas are cut to allow dulling and greening of the old cuts. Stands immediately adjacent to previous clearcuts should not be scheduled for a regeneration cut until a stand of trees has been established on the old cut. This difference in age will create variety and contrast in the sequence of cutover areas.

Where possible, consider cutting carefully selected trees or groups of trees or utilize clearcuts to open *vistas* through the timber. This can provide temporary or permanent views of outstanding physical features (rock outcrops, lakes, streams), and panoramas of the forest landscape. Leave clumps of birch, spruce, and other conifers to frame and give scale and dimension to the view. Vista openings need not be permanent. As changes occur in the forest scene, new openings can be developed to show the best views. Less attractive views can be allowed to close in.

Close control over harvest *operations* is as important as design. The best planning can be defeated by uncontrolled harvesting. The basic requirement is that the operation appear neat and organized. In all areas of heavy public use, harvesting should be limited to the minimum recreation season. In highly visible areas, harvest in the dormant season when leaves are absent to reduce the unsightliness of slash. Consider winter logging to avoid disturbance of ground vegetation. Stumps in the foreground should be low and the slash concealed by natural features, or lopped or chipped and scattered. Cut rather than girdle or herbicide trees in cultural treatments. In clearcuts, remove all standing trees that are dead, dying, damaged, culls, whips, or saplings (except for "special interest" trees). Remove all industrial debris from the operation. Keep damage from equipment and machinery to a minimum.

In site preparation, consider the visual impacts of the machinery and methods used. Skid trails, landings, and logging roads should flow with landforms and should be stabilized and seeded progressively as operations are completed. In locating landings, consider their potential use as wildlife openings, hunter parking areas, and campgrounds. Foregrounds are in effect display windows demanding more complete treatment and attention. Accomplishment of a workman-like job along travelways, waterways, use areas, and in aspen management operations in general will go a long way in meeting landscape objectives.

Figure 11. *These aspen clearcuts have been planned to minimize impact to the landscape by following irregular topographical and vegetation type boundaries, feathering edges, leaving special interest trees, and opening vistas.*

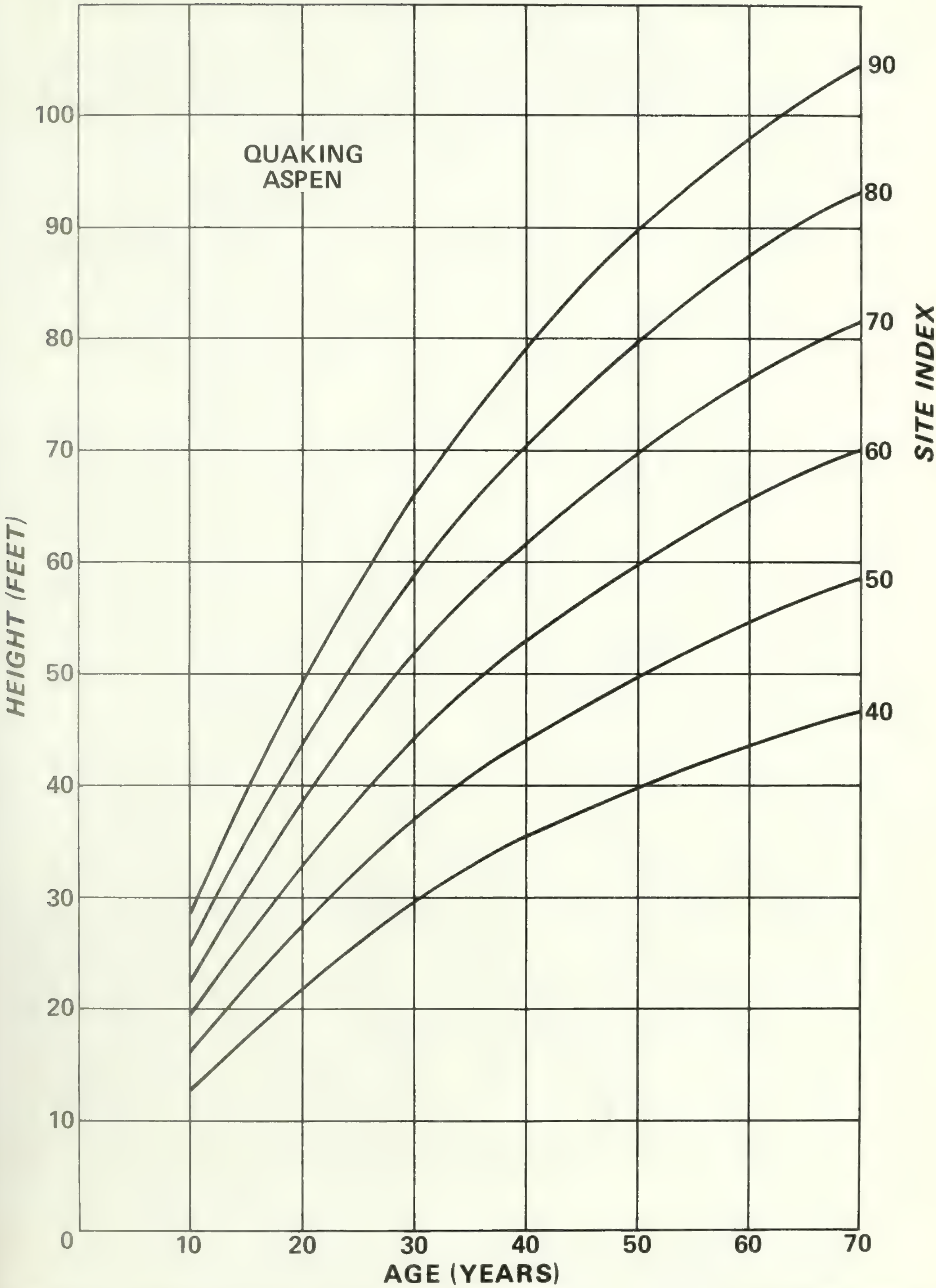

Figure 12. *Site index curves for quaking aspen in the north-central States (Lundgren and Dolid 1970).*

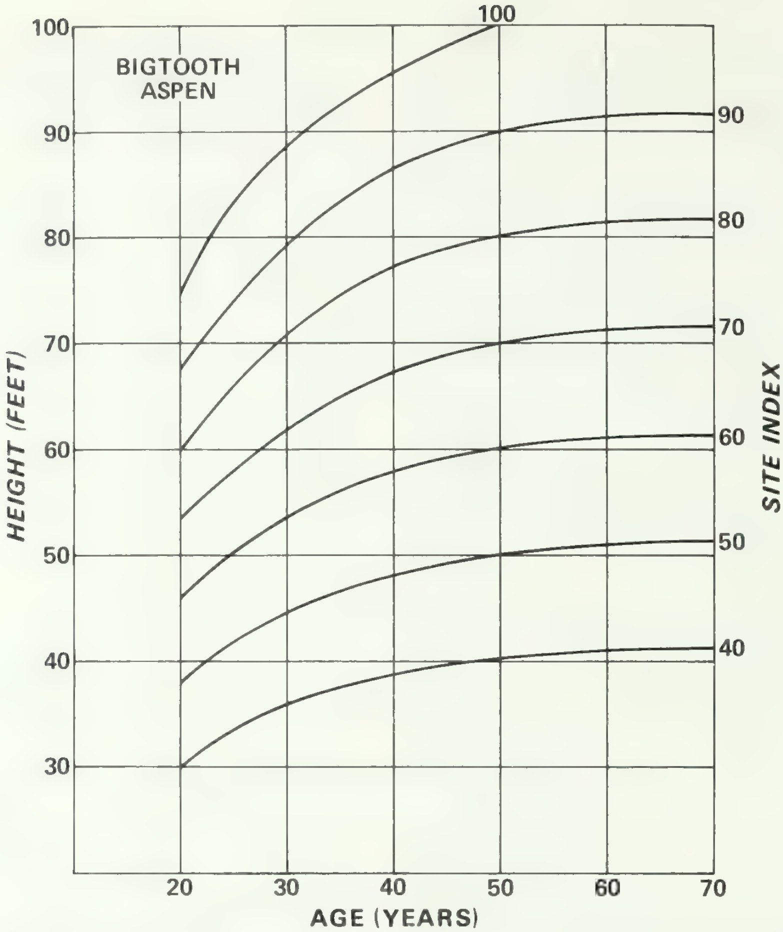

Figure 13. *Site index curves for bigtooth aspen in northern Lower Michigan (adapted from Graham* et al. *1963).*

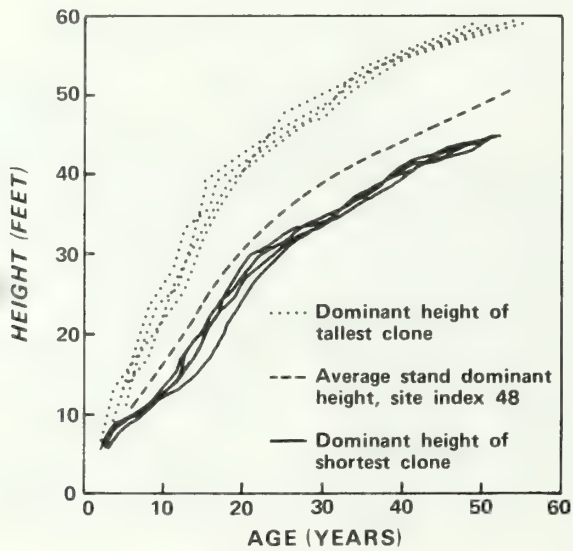

Figure 14. — *Height-age curves for the tallest and shortest clones of bigtooth aspen growing on the same site illustrating the need to sample more than one clone for site index determination (Zahner and Crawford 1963).*

Table 1. – *Estimated site index for quaking aspen in the Lake States based on soil texture and moisture regime (Stoeckeler 1960)*

Moisture regime	Percent silt-plus-clay in top 36 inches: <10	10-20	21-50	51-70	71+
	Height at 50 years, feet[1]				
Water table 2.5 to 8 feet	70	70	70	70	70
Well drained[2], with improved water holding capacity[3]	65	70	75	80	70
Well drained[2]	50	60	70	80	70
Poorly aerated[4]	60	60	60	50-60	50-60
Excessively drained[5]	40	40	55	70	70

[1]Calcareous parent material will increase site index about 5 feet. Stands exposed to wind or subject to rapid surface drainage (ridges, knolls) or on the upper half of 30 percent slopes with SE, S, SW, or W aspects will have 10 to 15 feet lower site index.

[2]No strong mottling within 1 foot of surface. Water tables deeper than 8 feet.

[3]Underlain at 2 to 3 feet with soils of greater water holding capacity (30 to 90 percent silt + clay).

[4]Strong mottling within 1 foot of surface, or water table closer than 2.5 feet.

[5]Droughty gravel is within 2 to 3 feet of surface soil and greater than 3 feet in thickness. Also includes soils where rock content exceeds 50 percent of the top 3-foot soil volume.

Table 2. – *Estimated site index for bigtooth or quaking aspen*[1] *on well-drained sandy soils, northern Lower Michigan (adapted from Graham* et al. *1963)*

Topography	Soil moisture category: Permeable subsoil, dry to 5 feet in summer	Depth to impermeable stratum[2]: 12 inches or less	13 inches to 18 inches	19 inches to 5 feet	Subsoil mottled	Water table within 5 feet
	Height at 50 years, feet[3]					
Flat uplands	30	30	40-50	50-60	60-70	70-80
Brow of slope	30-40	30-40	30-50	40-50	50-60	60-70
Upper slope: steep	30	30	30-40	40-50	50-60	60-70
Upper slope: moderate	30-40	30-40	30-50	40-50	50-60	60-70
Upper slope: gentle	30-40	30-40	30-50	40-60	50-70	70-80
Lower slope	30-40	40-50	50	60	70	80-90
Base of slope	30	40	50-60	60-70	80	90-100
Flood plain					80	80-100

[1]For quaking aspen reduce site index by 5 feet.

[2]Hardpans, clays, and fine compacted silts.

[3]Converging slopes or draws will raise site quality 10 feet above table values. Gravel (not washed layers) mixed in upper soil also will tend to raise site index. South-facing slopes will be lower than north-facing slopes. Where a range is given, the lower values are associated with coarse sands and the higher values with loamy sands; fine sands are intermediate.

Table 3. – *Effectiveness of harvesting and site preparation techniques for encouraging suckering*

Harvest option	Additional site preparation options available	Effectiveness for encouraging suckers where: Overstory contains noncommercial Conifers	Hardwoods[1]	Understory is brushy	Forest floor is sodded
Full-tree or tree-length system	Usually none needed	good	good	good	good
Shortwood system or No commercial harvest	Felling or girdling	good	good[3]	poor	poor
	Shearing	good	good	good	good
	Stem herbiciding	fair to good	good[3]	poor	poor
	Crown herbiciding (aerial)	poor	good[2]	fair	poor
	Prescribed burning	good[4]	good[4]	good	good

[1]Includes aspen.

[2]Recommended only for aspen, paper birch, and red oak.

[3]Do not girdle aspen in poorly stocked stands; fell instead to increase suckering.

[4]Effectiveness will be poor in unharvested stands with little ground fuel.

Prescribed Burning

At least 10 tons (fresh weight) of slash less than 3 ıches diameter are needed per acre for a burn hot nough to kill standing residuals. Generally, mature tands exceeding 60 to 80 square feet basal area will ave at least 10 tons of slash after conventional arvesting. The more evenly the slash is distributed, the ıore overstory will be killed. Stands that have not been arvested normally will not have sufficient fuel to burn ot enough to kill much of the overstory. In these cases re will nevertheless reduce understory competition and lacken the forest floor which will elevate spring soil emperatures to encourage suckering. Surviving trees — specially aspen — should be felled to maximize suckerıg.

An 8- to 12-foot wide fireline should surround the urn. Paper birches within 100 feet inside of the fireline ıould be felled to avoid burning birch bark being blown utside the line. After backfiring the downwind side of ıe burn, start headfires just upwind of the backfire in rogressive strips 50 to 100 feet wide. After a safe area as burned out, a single headfire can be lit from the pwind side.

Table 4 prescribes the burning weather needed for the nds of slash typical of harvested and unharvested aspen ands exceeding 60 to 80 square feet basal area will lculated by using the reference cited.

Forecasting Future Operability

To forecast the future operability of poorly stocked ands, estimate:

(1) Site index
(2) Present age
(3) Present number of live stems per acre over 6 inches ll
(4) Number of stems that died during the last year. These are easy to distinguish from stems that died rlier; leaf buds, fine twigs, and bark will be nearly tact compared to older mortality.)

Divide the number of dead stems by the total live *and* dead stems to estimate the present mortality rate.

Using the mortality rate and present age, use figure 15 to determine a *base number* of stems per acre.

Also, on figure 15 find a *correction factor* that corresponds to the site index.

Multiply the *base number* by the *correction factor* to determine the minimum number of stems per acre needed at present to assure a yield of 10 cunits per acre (total bolewood) at age 40.

An example: a site 70, age 10 stand has 2,000 live stems and 400 dead. The mortality rate is (400/2,000 + 400) = 0.17. Entering figure 15 we find the base number is approximately 3,500 (interpolate when necessary). Adjusting for site, 3,500 x 1.5 = 5,250 live stems are presently needed to yield 10 cunits per acre at age 40. Unless the mortality rate drops to about 0.14, 2,000 stems are inadequate. Therefore, this stand should be inspected annually to determine if the high mortality rate continues. Keep in mind that mortality can vary considerably from year to year so a several-year trend is needed to predict the probable fate of the stand.

For stands at age 20 or older, basal area is a more reliable indicator of future yields. These minimum basal areas are needed to assure 10 cunits per acre at age 40:

	Age		
	20	30	40
Site index	(minimum basal area, ft^2/acre)		
80	6	19	34
70	8	22	38
60	12	27	43
50	22	38	52

Figure 15 should be consulted also as described above to assess risk based on estimated mortality rate.

Table 4. — *Prescribed burning weather for aspen*

Observed and computed burning variables	Continuous slash (<25 percent conifer)	Continuous slash (≥25 percent conifer)	Little slash
Fuel Model[1]	D	I	F
Air temperature	>65°F	>50°F	>65°F
Relative humidity	<35 percent	<50 percent	<35 percent
Ignition component[1]	40-50	40-50	40-50
Energy release component[1]	14-17	14-17	6-8
Spread component[1]	4-7	2-6	2-4
Burning index[1]	13-21	10-21	3-4
Wind	6-12 mph	6-12 mph	6-12 mph
Number of days since rain exceeding 0.1 inch	>5	>3	>5

[1]See Deeming, *et al.* (1972) for description and calculation.

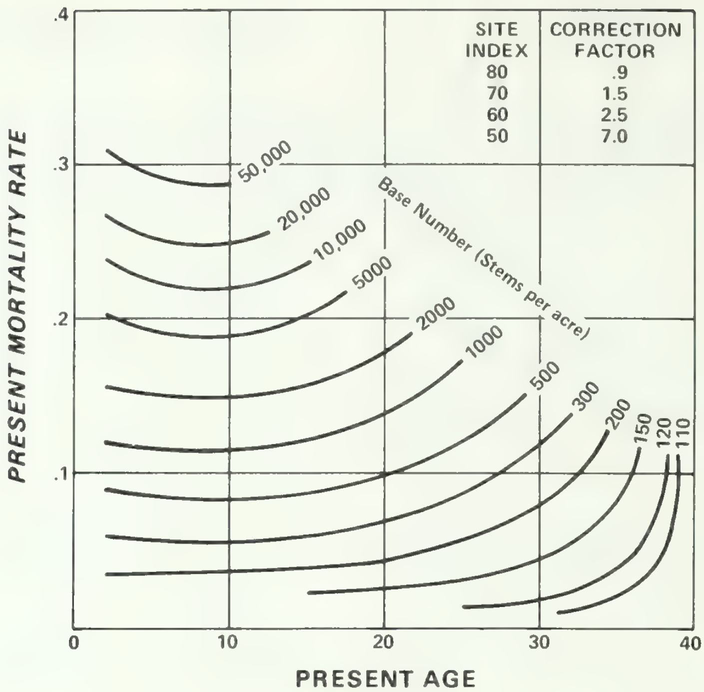

Figure 15. – *Minimum stocking chart for aspen to reach 10 cunits per acre at age 40, based on age, mortality rate, and site index.*

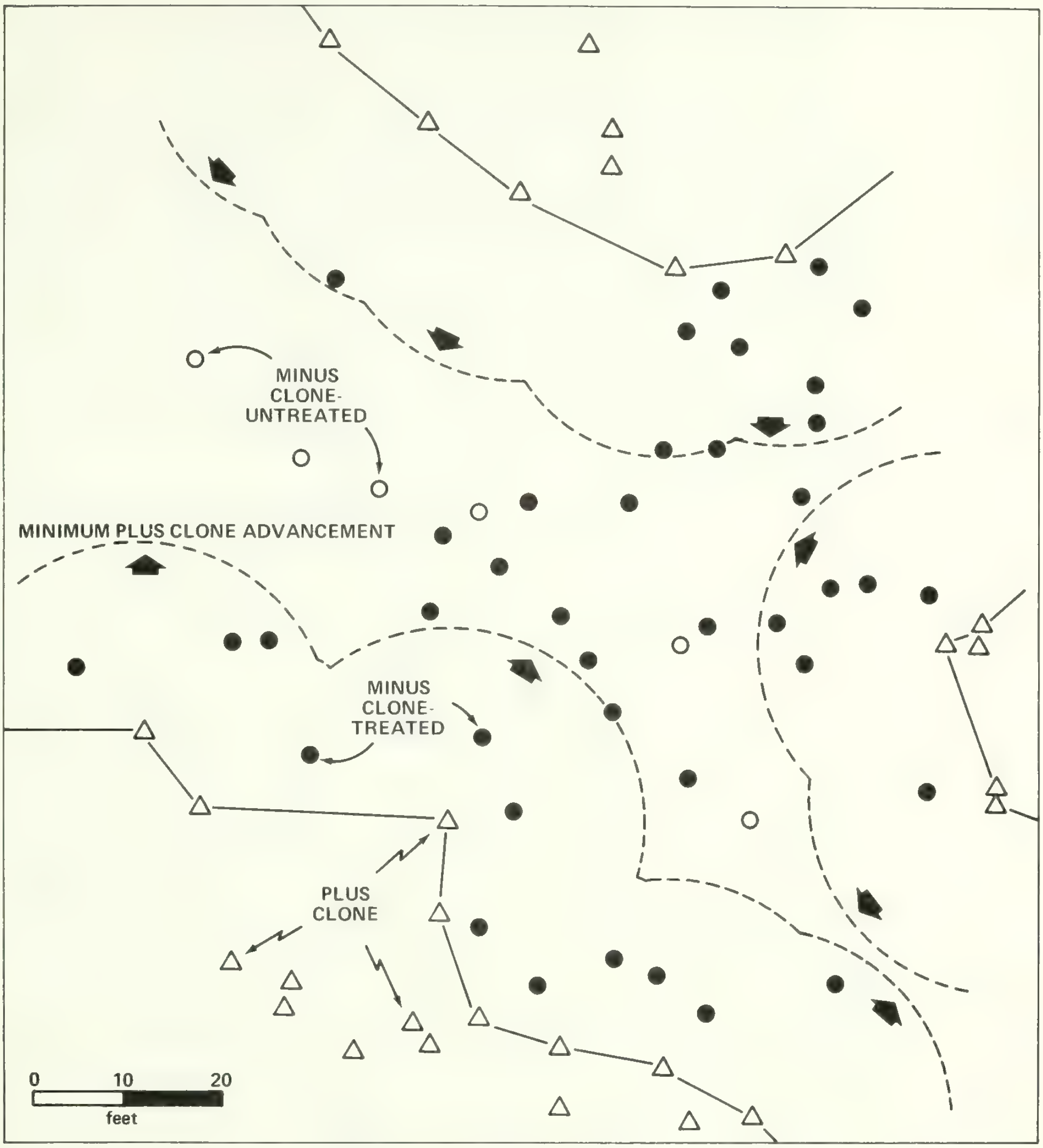

Figure 16. – *Management scheme to increase the extent of plus clones. Killing the minus trees will allow the plus clones to sucker and extend in the direction of the arrows. The untreated minus trees are needed to provide full sucker stocking outside of the minimum effective suckering range (20 feet) of the plus clones. This example is for a previously unthinned stand, age 50.*

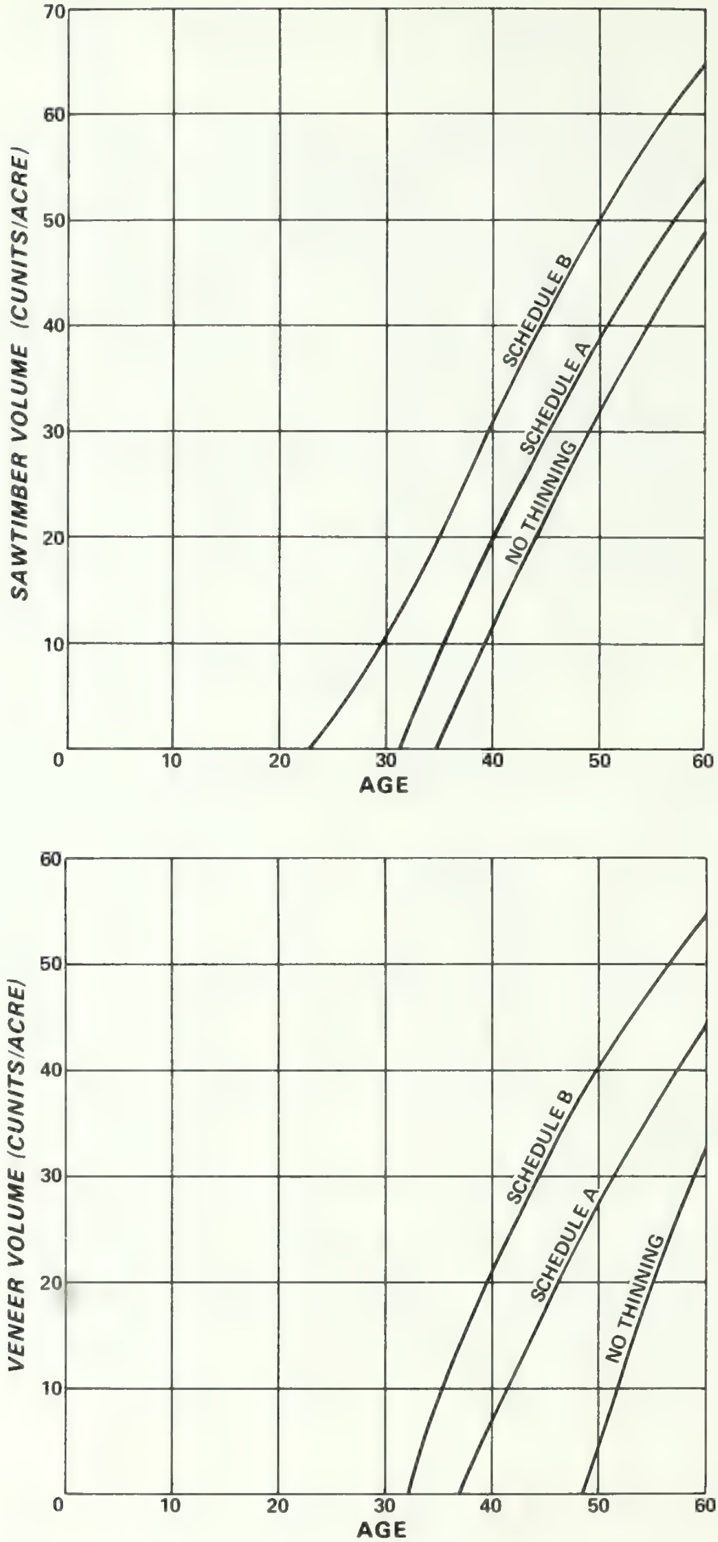

Figure 17. – *Example of yields from two thinning schedules. Schedule A = one commercial thinning, and Schedule B = one precommercial thinning plus one commercial thinning, compared to no thinning in site index 80 quaking aspen. (a) Merchantable yields of sawtimber, and (b) merchantable yields of veneer. No deductions have been made for defect.*

Table 5. – *Rotation ages*[1] *for aspen in the Lake States based on culmination of mean annual increment*

Site Index	Product: Fiber – Chips	Product: Fiber – Bolt to 4-inch top[2]	Product: Sawtimber 6-inch top	Product: Veneer 8-inch top
Without Thinning				
Feet	*Rotation age, years*			
50	35	NOT RECOMMENDED	NOT RECOMMENDED	NOT RECOMMENDED
60	35	60	NOT RECOMMENDED	NOT RECOMMENDED
70	35	55	60	NOT RECOMMENDED
80+	30	50	60	70
With Thinning				
70	NOT RECOMMENDED	NOT RECOMMENDED	60	NOT RECOMMENDED
80	NOT RECOMMENDED	NOT RECOMMENDED	50	

Estimating Growth and Yield

Estimating Yield

Yields in this handbook are in units most commonly used for each particular product. Whole-tree chips are in fresh weight tons. Pulpwood is in cords to a 4-inch top, and sawtimber and veneer is in cunits to 6- and 8-inch tops, respectively (all inside bark). These units can be converted from one to the other (table 6).

Stand volumes and weights can be estimated using stand basal area and mean stand height (table 7). (Mean stand height is the height of the tree of mean basal area, and can be determined from d.b.h./height curves, or by summation of heights weighted by d.b.h.^{2}, divided by the sum of d.b.h.^{2}.)

Next, the yield of pulpwood, sawtimber, and veneer can be estimated by multiplying the bole volume or weight from table 7 by the merchantable bole ratios in table 8. For example, a stand with 120 square feet basal area per acre, mean stand height of 80 feet, and mean stand d.b.h. of 9 inches will yield 39 cunits of bolewood, or 114 tons fresh weight of bolewood and bark per acre (from table 7). The merchantable bole ratios for pulpwood, sawtimber, and veneer are 0.91, 0.65, and 0.17, respectively (from table 8). The merchantable yield then is 39 cunits x 0.91 = 35 cunits pulpwood; 39 x 0.65 = 25 cunits sawtimber and 39 x 0.17 = 7 cunits veneer. Fresh weights are converted similarly. For direct conversion to cords in this example, the ratio is 1.15 (table 8). Therefore the stand has 39 x 1.15 = 45 cords per acre.

Predicting Growth

To project basal area 10 years in the future for quaking aspen stands, use table 9.

Future mean stand height can be predicted by following site index curves (fig. 12).

Using projected basal area (table 9) and projected height (fig. 12), projected yield may be taken from table 7. Mean stand diameter will increase 1.8 inches in 10 years. From projected yield and mean stand diameter, projected merchantable yields can also be estimated using table 8.

"Normal" yields for fully stocked aspen stands without thinnings are found in table 10 for quaking aspen and table 11 for bigtooth aspen in northern lower Michigan. (When this table is used elsewhere for bigtooth aspen, the growth estimates are likely to be less accurate.) These tables help determine the average growth and yield expected of well-stocked stands. Growth and yield of individual stands will be proportionate to basal area stocking.

Table 6. - *Conversion factors. Multiply unit measures in "from" column by factors in body of table to get unit measures in "to" columns*

From		To: Whole-tree chips (tons) Dry	Whole-tree chips (tons) Fresh	Clean chips (tons) Dry	Clean chips (tons) Fresh	Cords	Cunits[1]
		Multiply by					
Whole-tree chips, (tons)	Dry	1.00	1.95	0.77	1.52	0.85[2]	0.78[2]
	Fresh	.51	1.00	.38	.77	.43[2]	.40[2]
Clean chips, (tons)	Dry	1.30	2.61	1.00	1.98	1.04[3]	.82[3]
	Fresh	.66	1.30	.50	1.00	.53[3]	.41[3]
Cords		1.17[2]	2.31[2]	.96[3]	1.89[3]	1.00	.79
Cunits		1.28[2]	2.51[2]	1.22[3]	2.44[3]	1.27	1.00

[1] 1 cunit equals 100 cubic feet.
[2] Includes wood and bark.
[3] Includes wood only.

For example, 100 dry tons of wood in clean chips (without bark), are contained in 130 tons of whole-tree chips (with bark) if dry, or from 261 tons if fresh. This 100 tons is also equivalent to 198 tons of fresh clean chips, 104 cords and 82 cunits.

Table 7. — *Gross bolewood volume without bark (cunits), bolewood + bark fresh weight (tons), and complete tree fresh weight (tons); all per acre; all trees greater than 0.6-inch d.b.h. (Schlaegel 1975)*

Stand basal area	Mean stand height, ft							
	30	40	50	60	70	80	90	100
ft²/acre								
20	2[1]	3	4	5	6	7	7	8
	7[2]	9	12	14	17	19	21	24
	9[3]	11	14	17	20	23	25	28
40	5	6	8	10	11	13	15	16
	14	19	24	28	33	38	43	47
	17	23	28	34	39	45	50	56
60	7	10	12	15	17	20	22	25
	21	28	36	43	50	57	64	71
	25	34	42	50	59	67	75	83
80	10	13	16	20	23	26	29	33
	28	38	47	57	66	75	85	94
	34	45	56	67	78	89	100	111
100	12	16	20	25	29	33	37	41
	36	47	59	71	82	94	106	118
	42	56	70	84	98	111	125	138
120	--	20	25	30	34	39	44	49
	--	57	71	85	99	114	128	142
	--	67	84	100	116	133	150	166
140	--	23	29	34	40	46	51	57
	--	66	82	99	116	132	148	165
	--	78	98	116	136	155	174	193
160	--	--	33	39	46	52	59	65
	--	--	94	113	132	151	170	188
	--	--	111	133	155	177	199	220
180	--	--	37	44	51	59	66	73
	--	--	106	128	148	170	191	212
	--	--	125	150	174	199	224	248
200	--	--	41	49	57	65	73	82
	--	--	118	142	165	188	212	236
	--	--	138	166	194	220	248	275
220	--	--	45	54	63	72	81	90
	--	--	130	156	182	208	234	259
	--	--	152	182	212	242	272	302
240	--	--	49	59	68	78	88	98
	--	--	142	170	198	226	254	282
	--	--	166	199	232	264	296	329

[1]Bolewood volume from 6-inch stump to tip of tree.

[2]Bolewood + bark fresh weight from 6-inch stump to tip of tree.

[3]Complete tree fresh weight, including branches, from 6-inch stump to tip of tree.

Note: The values in Table 7 can be estimated quite accurately from stand basal area (B) and dominant stand height (H) by rules of thumb:

(1) $\frac{4\ (BxH)}{1000}$ = bolewood volume, cunits (without bark)

(2) $\frac{BxH}{80}$ = bolewood + bark fresh weight, tons

(3) $\frac{BxH}{70}$ = total tree fresh weight, tons

Equation (1) will be 2 percent low, equations (2) and (3) will be 6 and 4 percent high, respectively.

Table 8. – *Merchantable bole ratios based on top diameter inside bark and mean stand diameter (adapted from Schlaegel 1974)*

Product	Top diameter inside bark, inches	Mean stand D.B.H., inches[1]										
		5	6	7	8	9	10	11	12	13	14	15
Cunit : cunit or ton : ton conversions												
Pulpwood	4	0.30	0.60	0.77	0.86	0.91	0.94	0.95	0.96	0.97	0.97	0.98
Sawtimber	6	--	--	.31	.50	.65	.76	.84	.90	.94	.97	.98
Veneer	8	--	--	--	--	.17	.42	.58	.69	.76	.80	.83
Cunit : peeled cord conversions												
Pulpwood	4	.38	.76	.97	1.09	1.15	1.19	1.20	1.22	1.23	1.23	1.24

[1]Mean stand d.b.h., inches = $\sqrt{\frac{183\ B}{N}}$, where B is stand basal area, square feet per acre, and N is number of trees per acre.

Table 9. – *Ten-year projected basal area per acre by present age and basal area for quaking aspen stands with a site index 70 and better[1] (adapted from Schlaegel 1971)*

Present stand age	Present basal area per acre						
	20	40	60	80	100	120	140
Years	- - - - - - *Square feet* - - - - - -						
20	44	71	92	112	130	147	163
30	36	61	83	103	122	140	157
40	32	56	78	98	117	135	153
50	30	53	75	95	114	133	151

[1]Includes all trees 0.6 inch d.b.h. and larger. Do not use for bigtooth aspen.

Table 10. – *Normal yield tables for quaking aspen; all trees 0.6-inch d.b.h. and larger (adapted from Brown and Gevorkiantz 1934; Schlaegel 1974, 1975)*

Age	Dominant height	Mean dbh	Number of trees per acre	Basal area per acre	Gross yield per acre: Complete tree	Gross yield per acre: 4-inch top[1]	Gross yield per acre: 6-inch top[1]	Gross yield per acre: 8-inch top[1]
Years	*Feet*	*Inches*		*Sq. Ft.*	*Tons fresh wt.*	*Cords*[2]	*Cunits*[2]	*Cunits*[2]
SITE INDEX 80								
20	44	3.3	1490	88	53	--	--	--
30	59	4.8	880	110	89	7	--	--
40	71	6.3	600	129	125	31	5	--
50	80	8.1	400	143	160	52	25	--
60	88	10.3	265	153	191	67	44	26
70	94	12.6	185	161	212	77	58	46
SITE INDEX 70								
20	38	2.9	1800	83	46	--	--	--
30	52	4.2	1065	102	76	--	--	--
40	62	5.4	760	120	105	17	--	--
50	70	7.0	495	133	138	39	12	--
60	77	9.0	330	144	163	55	31	8
70	82	10.9	235	151	184	65	45	31
SITE INDEX 60								
20	33	2.5	2300	76	37	--	--	--
30	44	3.5	1400	94	62	--	--	--
40	53	4.5	980	110	86	2	--	--
50	60	5.9	645	122	107	23	--	--
60	66	7.6	422	133	130	40	16	--
70	70	9.3	295	139	145	49	29	10
SITE INDEX 50								
20	28	1.9	3200	60	25	--	--	--
30	37	2.7	1910	75	40	--	--	--
40	44	3.5	1300	88	56	--	--	--
50	50	4.6	856	98	75	3	--	--
60	55	5.8	580	105	88	18	--	--
70	58	7.1	400	109	95	27	9	--
SITE INDEX 40								
20	22	1.3	4100	38	12	--	--	--
30	29	1.9	2420	46	20	--	--	--
40	35	2.4	1660	54	29	--	--	--
50	40	3.2	1110	60	37	--	--	--

[1] Top diameters are inside bark.

[2] Cords and cunits are without bark.

Table 11. *Normal yield tables for bigtooth aspen in northern Lower Michigan; all trees 0.6-inch d.b.h. and larger (adapted from Graham* et al. *1963)*

Age	Dominant height	Mean dbh	Number of trees per acre	Stand basal area per acre	Gross yield per acre: Complete tree	Gross yield per acre: 4-inch top[1]	Gross yield per acre: 6-inch top[1]	Gross yield per acre: 8-inch top[1]
Years	*Feet*	*Inches*		*Square feet*	*Tons fresh wt.*	*Cords*[2]	*Cunits*[2]	*Cunits*[2]
SITE INDEX 80								
30	71	7.4	460	139	133	40	15	--
40	77	8.8	360	152	159	53	29	5
50	80	9.8	268	140	151	53	33	17
60	81	10.5	209	126	137	49	33	21
SITE INDEX 70								
30	62	6.6	460	110	92	25	--	--
40	67	8.0	360	127	116	37	17	--
50	70	8.8	295	123	118	39	21	4
60	71	9.2	240	112	108	37	21	7
SITE INDEX 60								
30	53	5.9	466	90	65	14	--	--
40	58	7.3	366	107	84	25	9	--
50	60	8.0	313	108	88	28	13	--
60	61	8.2	273	101	84	27	13	--
SITE INDEX 50								
30	45	5.1	495	70	43	5	--	--
40	48	6.6	380	89	59	15	--	--
50	50	7.1	330	90	63	18	6	--
60	51	7.3	295	86	61	18	7	--
SITE INDEX 40								
30	36	4.0	540	48	24	--	--	--
40	39	5.7	407	71	39	7	--	--
50	40	6.2	357	76	41	10	--	--
60	41	6.2	313	65	37	9	--	--

[1] Top diameters are inside bark.
[2] Cords and cunits are without bark.

Metric Conversion Factors

convert	*to*	*Multiply by*
es	Hectares	0.405
rd feet[1]	Cubic meters	0.005
rd feet/acre[1]	Cubic meters/hectare	0.012
ins	Meters	20.117
ds[1]	Cubic meters	2.605
ds/acre[1]	Cubic meters/hectare	6.437
ic feet	Cubic meters	0.028
ic feet/acre	Cubic meters/hectare	0.070
rees Fahrenheit	Degrees Celsius	[2]
t	Meters	0.305
lons	Liters	3.785
lons/acre	Liters/hectare	9.353
hes	Centimeters	2.540
es	Kilometers	1.609
es/hour	Meters/second	0.447
ber/acre	Number/hectare	2.471
ces	Grams	28.350
ces/acre	Grams/hectare	70.053
nds	Kilograms	0.454
nds/acre	Kilograms/hectare	1.121
nds/gallon	Kilograms/liter	0.120
are feet	Square meters	0.093
are feet/acre	Square meters/hectare	0.230
s	Metric tons	0.907
s/acre	Metric tons/hectare	2.242

[1]The conversion of board feet and cords to cubic ers can only be approximate; the factors are based an assumed 5.663 board feet (log scale) per cubic t and a cord with 92 cubic feet of solid material.

[2]To convert °F to °C, use the formula 5/9 (°F-32) $\frac{°F-32}{1.8}$.

Common and Scientific Names of Plants and Animals

Plants

Aspen:
- Bigtooth . . . . *Populus grandidentata*
- Quaking . . . . *Populus tremuloides*

Balsam fir . . . . *Abies balsamea*
Heart rot . . . . *Phellinus igniarius*
Hypoxylon canker . . . . . . *Hypoxylon mammatum*
Maple:
- Red . . . . *Acer rubrum*
- Sugar . . . . *Acer saccharum*

Northern white-cedar . . . . *Thuja occidentalis*
Paper birch . . . . *Betula papyrifera*
Pine:
- Jack . . . . *Pinus banksiana*
- Red . . . . *Pinus resinosa*
- White . . . . *Pinus strobus*

Shepherd's crook . . . . . . *Venturia tremulae*
White spruce . . . . *Picea glauca*

Animals

Bald eagle . . . . *Haliaeetus leucocephalus*
Beaver . . . . *Castor canadensis*
Black bear . . . . *Ursus americanus*
Borers:
- Poplar . . . . *Saperda calcarata*
- Miscellaneous . . . . *Saperda* spp., *Agrilus* spp., *Oberea* spp.

Eastern timber wolf . . . . . *Canis lupus*
Forest tent caterpillar . . . *Malacasoma disstria*
Great horned owl . . . . . . *Bubo virginianus*
Large aspen tortrix . . . . . *Choristoneura conflictana*
Osprey . . . . *Pandion haliaetus carolinensis*
Ruffed grouse . . . . *Bonasa umbellus*
Snowshoe hare . . . . *Lepus americanus*
White-tailed deer . . . . . . *Odocoileus virginianus*

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key – out of the reach of children and animals – and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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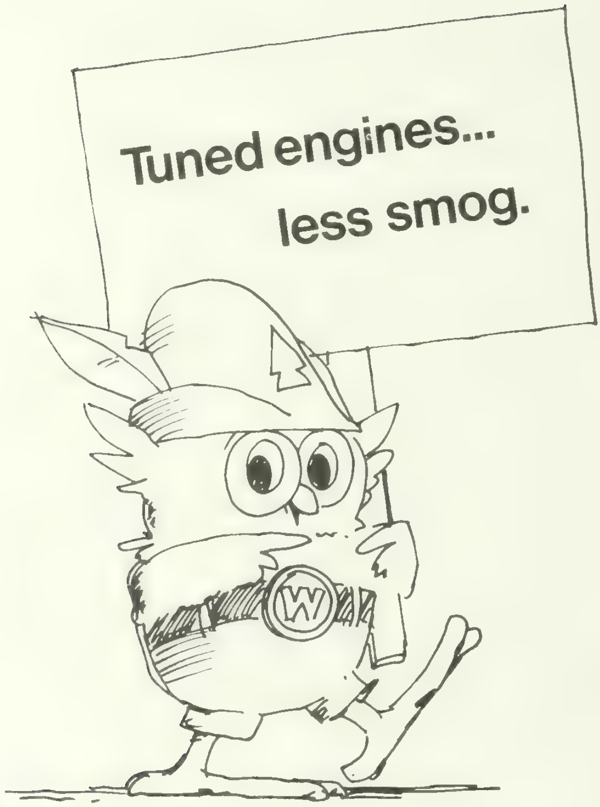
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managers handbook for

OAKS IN THE NORTH CENTRAL STATES

GENERAL TECHNICAL REPORT NC-37

NORTH CENTRAL FOREST EXPERIMENT STATION FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

Other Manager's Handbooks are:

- Jack pine – GTR-NC-32
- Red pine – GTR-NC-33
- Black spruce – GTR-NC-34
- Northern white-cedar – GTR-NC-35
- Aspen – GTR-NC-36
- Black walnut – GTR-NC-38
- Northern hardwoods – GTR-NC-39

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FOREWORD

This is one of a series of manager's handbooks for important forest types in the north central States. The purpose of this series is to present the resource manager with the latest and best information available on handling these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. However, ways to modify management practices to maintain or enhance other values are included where sound information is available.

The author has, in certain instances, drawn freely on unpublished information provided by scientists and managers outside his specialty. He is also grateful to the several technical reviewers in the region who made many helpful comments.

The handbooks have a similar format, highlighted by a "Key to Recommendations". Here the manager can find in logical sequence the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbook. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objective. The manager should also apply new research findings as they become available so that the culture of these important forest types can be continually improved.

CONTENTS

OAKS
IN THE NORTH CENTRAL STATES

Ivan L. Sander, *Principal Silviculturist*
Columbia, Missouri

INTRODUCTION

is handbook applies to the broad upland forest iation commonly called oak-hickory. The oaks, , white, northern red, scarlet, chestnut, post, and jack predominate, and occur in widely varying ures with each other and with many other species Appendix V, table 21, for scientific names of plants animals). Hickories are consistently present in this iation but are not generally abundant. The repro- on requirements for hickory are essentially the as those for oak, and although hickories are ently slower growers than oaks, they require about ame growing space for good diameter and volume growth. Because oaks are by far most abundant, this guide is written in terms of oaks rather than oak-hickory.

The handbook was prepared to apply specifically to the north central States of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin. However, the oaks or oak-hickory type occurs extensively over the eastern United States, and the principles on which the handbook is based generally apply wherever oak stands grow. Outside the north central States, however, the recommendations may need to be modified, so they should be applied with caution.

SILVICAL HIGHLIGHTS

ks are found over a wide range of soil and graphic conditions, from sandy, rocky soils to heavy soils, and from dry upper slopes and ridges to moist slopes and coves. Best growth occurs on moist drained soils in coves and on middle and lower s.

s grow in association with many other tree and species. Among their most important tree associ- re the hickories, blackgum, red and sugar maples, v-poplar, white ash, black cherry, basswood, and walnut. Common understory tree and shrub ates include flowering dogwood, sassafras, eastern ornbeam, American hornbeam, blueberry, hazelnut, itchhazel.

s start to bear fruit at about age 25. Good seed are produced at intervals of 2 to 10 years; there may be complete failures some years. Acorn numbers vary widely by years and by trees within the same stand.

Acorns of species in the white oak group germinate soon after falling; those of species in the red oak group germinate the spring after seedfall. Best germination occurs in mineral soil under a light covering of leaves.

To successfully produce new oak stands after harvest cuttings, relatively large oak stems (advance reproduction) must be present before the old stand is harvested. These stems will generally be sprouts that typically have died back to the ground and resprouted several times. So, the stem is usually many years younger than the root system. When such stems are cut off or damaged during harvest, a new sprout appears that will grow rapidly in full sunlight. These new sprouts are the most desirable

type of oak reproduction in stands that develop after clearcutting or the final removal cut in shelterwood cuttings.

The frequency of sprouting from stumps varies somewhat among oaks. Black and white oaks generally sprout less frequently than northern red, scarlet, or chestnut oaks; small stumps sprout more frequently than large ones. Sprouts that originate at or below ground level and from small stumps are less likely to develop heartwood decay.

The juvenile height growth of new oak sprouts is related to the size of the old stem from which th originate. Sprouts from large stems grow faster th sprouts from small stems. Oaks respond well to rele unless they are overtopped or have grown in de stands for long periods of time. Sapling and pole-s trees that are dominant or codominant respond best a grow rapidly when given enough space.

Epicormic sprouting may be heavy on oaks that h grown in fully stocked stands for 20 years or more a then given sudden and heavy release. Dominant a codominant trees are less likely to produce as ma epicormic sprouts as intermediate or suppressed trees.

MANAGEMENT OBJECTIVES AND NEEDS

Growing full yields of the highest value products the site can produce in a relatively short time is the management objective considered in this handbook. Most of the product volume will be in high quality sawtimber and some veneer quality trees, but pulpwood and other small roundwood products will be harvested from thinnings or as the final crop, especially on poor sites. Where the objective is to manage for a resource other than timber, or for any combinations of timber, water, wildlife, recreation, and range, the recommendations in this handbook should be modified as needed.

To achieve the objective of producing high qual sawtimber and veneer trees, even-aged silviculture a management are recommended. Prompt regeneration needed and our present knowledge suggests that thi best attained through clearcutting or some form shelterwood. But silvicultural knowledge for inten management is not complete. Techniques need to further developed to ensure adequate regeneration, a yield tables for managed stands need much refineme

KEY TO RECOMMENDATIONS

The following key describes some of the management options and silvicultural alternatives that will lead to efficient timber production. Every possible situation cannot be presented in detail, so the silviculturist must choose the alternative that best fits the situation. The key does not consider uses other than timber. However, where necessary, the silvicultural recommendations can be modified according to the information in the section on other resource considerations.

Starting with the first pair of numbered statements, select the statement that better describes the stan question. Each statement will give either a numbe partial recommendation and a number, or a fi recommendation. If a number is given, repeat selection process until a final recommendation reached. The overall recommendation is the sum of partial recommendations arrived at while going thr the key. Turn to the page and letter references in "Timber Management Considerations" section for m detail on management options and silvicultural tr ments.

1. Oak site index 75 or greater . . . .

1. Oak site index less than 75 . . . .

2. Stand in "Driftless Area" of Wisconsin, Minnesota, and northeastern Iowa, or northern Lower Michigan (See p. 4, A) . . . .

2. Stand not in above areas . . . .

3. Stand mature (more than 50 percent of basal area in trees that have reached the desired size for the site) . . . . CONVERT TO OTHER HARDWOOD

3. Stand immature (less than 50 percent of basal area in trees that have reached the desired size for the site) . . . .

4. Seed source or advance reproduction of other desirable hardwoods present . . . . REMOVE OAK OVERSTORY USING SHELTERWOOD CUT, *or* CLEARCUT (See p. 10, R)

4. Seed source or advance reproduction of other desirable hardwoods absent . . . . HARVEST AND INTERPLANT WHITE ASH, SUGAR MAPLE, OR OTHER SUITABLE SPECIES (See p. 10, R)

Stand basal area two-thirds or more in oak . . . . MANAGE FOR OAK OR MIXED OAK – OTHER HARDWOODS (See p. 9, P)

Stand basal area one-third or less in oak . . . . MANAGE OTHER DESIRABLE HARDWOODS (See p. 9, P)

6. Stand in southern Illinois, southern Indiana, or southern Lower Michigan . . . . (See p. 4, A) . . 7

6. Stand in Ozarks region of Missouri . . . . MANAGE FOR OAKS (See p. 4, A) . . 12

Stand mature (more than 50 percent of basal area in trees that have reached the desired size for the site) . . . . CONVERT TO OTHER HARDWOODS OR MIXED OAK – OTHER HARDWOODS (See p. 10, S)

Stand immature (less than 50 percent of basal area in trees that have reached the desired size for the site) 8

8. Stand basal area 50 percent or more in oaks . . . . MANAGE FOR OAK OR MIXED OAK – OTHER HARDWOODS (See p. 9, P)

8. Stand basal area less than 50 percent in oaks . . . . MANAGE FOR MIXED OAK – OTHER HARDWOODS OR OTHER HARDWOODS (See p. 9, P)

Oak site index 65 through 74 10

Oak site index less than 65 11

10. Stand in southern Illinois, southern Indiana, "Driftless Area" of Minnesota, Wisconsin, and Iowa, or Lower Michigan . . . . MANAGE FOR OAK OR MIXED OAK–OTHER HARDWOODS (See p. 4, B; p. 9, P) . . 12

10. Stand in Ozarks region of Missouri or elsewhere . . . . MANAGE FOR OAKS (See p. 4, B) . . 12

Oak site index 55 through 64 . . . . MANAGE FOR OAK OR MIXED OAK–PINE (See p. 4, B; p. 10, Q) . . 12

Oak site index less than 55 . . . . CONVERT TO PINE *or* DO NOT MANAGE (See p. 5, C; p. 10, T)

12. Stand mature (more than 50 percent of basal area in trees that have reached the desired size for the site) (See p. 6, D) 13

12. Stand immature (less than 50 percent of basal area in trees that have reached the desired size for the site) (See p. 7, H) . . . 14

Oak advance reproduction adequate . . . . HARVEST (See p. 6, E)

Oak advance reproduction inadequate . . . . ESTABLISH AND DEVELOP OAK ADVANCE REPRODUCTION (See p. 6, F)

14. More than 50 percent of stand basal area in one size class 15

14. No single size class contains more than 50 percent of stand basal area (See p. 9, K) 19

More than 50 percent of stand basal area in saplings or pole size trees (See p. 9, I) . . . REDUCE STOCKING TO NOT LESS THAN 60 PERCENT; THIN AT 10-YEAR INTERVALS

More than 50 percent of stand basal area in sawtimber size trees (See p. 9, J) 16

16. Stand fully stocked (total stocking 60 percent or higher) 17

16. Stand understocked (total stocking less than 60 percent) or of poor quality . . . . REHABILITATE *or* REGENERATE (See p. 9, O)

More than half of trees at least 80 percent of desired rotation diameter (See p. 9, L) 18

More than half of trees less than 80 percent of desired rotation diameter . . . . THIN *or* WAIT (See p. 9, N)

18. Stocking 80 percent or more . . . . THIN LIGHTLY TO ENHANCE OAK ADVANCE REPRODUCTION (See p. 9, L)

18. Stocking 60 through 79 percent . . . . WAIT (See p. 9, M)

More than 50 percent of basal area in saplings and poles . . . . . . COMBINE SAPLINGS/POLES INTO ONE CLASS (See p. 9, K)

More than 50 percent of basal area in poles and sawtimber . . . . COMBINE POLES/SAWTIMBER INTO ONE CLASS (See p. 9, K)

TIMBER MANAGEMENT CONSIDERATIONS

Stand Size

A number of factors must be considered when ing the size of a stand and delineating its bounda- There is no silvicultural reason to set an upper limit for stand size, but *there are* silvicultural reasons to limit the minimum size. When an old stand is completely removed, the new stand develops in the opening. In every opening there is a zone around the edge in which growth of the new stand is retarded by the surrounding

stands. For best development of the new reproduction the proportion of the stand area in this zone should be kept as low as possible. As stand size is reduced below about 2 acres the percent of area in this zone increases rapidly. Thus, for silvicultural reasons the minimum stand size should be 2 acres (for metric equivalents, see p. 33, Appendix V).

Silvicultural prescriptions are easier when a stand is relatively uniform and occupies relatively uniform site conditions. The stand should be large enough so it can be readily mapped and entered into records, and so it can be accurately located for future silvicultural operations. Stand size can be smaller for small forest properties than for larger properties because on small properties small stands are easier to keep track of.

Site Quality

For the purpose of this handbook three broad site classes have been recognized. Good sites are those with a site index for oak of 75 or more, average sites have an oak site index of 55 to 74, and the oak site index for poor sites is 40 to 54.

In determining site index, local site index curves should be used if available. In areas where local curves are not available, regional curves or tables can be used (see Appendix I, tables 4 and 5, figs. 1-6). Site index should be estimated directly from height-age measurements if suitable trees are present. Trees selected should be single-stemmed, dominant or codominant, and show no signs of past suppression.

If suitable trees for direct estimation of site index are not available, site index may be estimated from soil and topographic features in areas where soil-site relations have been studied and correlations made (Appendix I, tables 6-10).

Site-Species Relations

Oaks occur in varying mixtures over the entire range of upland sites in the north central States. Other hardwood species may occur in mixture with the oaks, especially on the good sites, and on average to poor sites pines may be present. The preferred species for timber production are listed in table 1.

A. On good sites (oak site index 75+), the opportunities to manage for oak will vary according to geographic location. It will often be difficult and probably impractical to perpetuate essentially pure oak stands in many areas on these sites.

In the "Driftless Area"[1] of southwestern Wiscons southeastern Minnesota, and northeastern Iowa and northwestern Lower Michigan, existing northern red stands and the northern red oak-white oak mixture ecologically unstable. The trend is toward species ot than oaks. Sugar maple, American elm, American b wood, white ash, and black cherry usually beco established under present oak stands, while oak adva reproduction is scarce to nonexistent. In these ar managing for oaks beyond the life of presently exist stands may not be practical. Establishing adequate advance reproduction will be extremely difficult costly because of the severe competition from ot species. Future stands will contain some northern and white oaks of stump sprout origin, but the event domination of these sites by more mesic species inevitable. Consider managing succeeding stands as m tures of oaks and other hardwoods (see P, p. 9), o converting these sites to other hardwoods (see R, p.

In southern Illinois, southern Indiana, and in parts Lower Michigan, yellow-poplar and other intoler species will increase as the present oak stands harvested. Future stands will probably always cont some oaks; the proportion will depend on the amo and size of the oak advance reproduction present w the harvest cut is made. These stands should be mana as mixtures. It may be possible to manage for essenti pure yellow-poplar on these sites, but weedings by 10 will probably be necessary.

In the Ozarks region of Missouri, desirable non timber species are limited and oaks will continue to the species to manage for on good sites. Even so, spe measures may be necessary to ensure establishment development of adequate oak advance reproduction.

B. The average sites (site index 55 to 74) are suited to oak management, and the perpetuation of anywhere in the region should not be too diffi except for sites near the upper limit of the class. As site index increases from about 65 to 74, yellow-po and other intolerant or more mesic species will incr in southern Illinois and Indiana. In the Driftless and in Lower Michigan species such as American sugar maple, white ash, and American basswood increase where adequate seed sources exist becaus their ability to become established and persist in understory. Oaks will probably be present in the sta that follow harvest cutting because of their ability sprout. In these situations consider managing mixt of oaks and other hardwoods.

[1] *The hilly, unglaciated portions of these States.*

Table 1. – *Preferred species for management by region and site index*

Region	Site index class	Preferred oaks	Preferred associated species
	Feet		
Missouri Ozarks	75+	N. Red Oak Black Oak White Oak	Black Walnut Hickories
	55-74	Black Oak White Oak N. Red Oak Scarlet Oak	Black Walnut Hickories Shortleaf Pine
	40-54	Scarlet Oak Black Oak White Oak N. Red Oak	Hickories Shortleaf Pine
Southeastern Minnesota, southern Wisconsin, northeastern Iowa	75+	N. Red Oak White Oak	White Ash Sugar Maple American Basswood Butternut Black Walnut
	55-74	N. Red Oak Black Oak White Oak	White Ash Sugar Maple Black Walnut American Basswood White Pine Red Pine
	40-54	Black Oak White Oak Bur Oak	Hickories Red Pine
Lower Michigan	75+	N. Red Oak White Oak	American Basswood Black Cherry White Ash Sugar Maple Black Walnut Yellow Poplar
	55-74	N. Red Oak Black Oak White Oak	White Ash American Basswood Sugar Maple Hickories
	40-54	Black Oak White Oak N. Pin Oak	Aspen Jack Pine Red Pine Red Maple
Southern Illinois, southern Indiana	75+	N. Red Oak Black Oak White Oak	Yellow Poplar White Ash Black Walnut
	55-74	N. Red Oak Black Oak White Oak Chestnut Oak	Yellow Poplar White Ash Black Walnut Hickories
	40-54	Black Oak Chestnut Oak Scarlet Oak White Oak	Hickories

M agement for essentially pure oak on these sites ou d be feasible anywhere in the region, except as te above. However, special measures may be neces- y o ensure establishment and development of ade- at oak advance reproduction.

In the Ozarks and in Lower Michigan, mixtures of pine and oak are sometimes present on these sites. It should be feasible to manage these stands as mixtures.

C. The poor sites (site index 40 to 54) are almost exclusively occupied by oaks. Stands are often of poor

quality, and dominated by the less desirable oaks such as post and blackjack oak in Missouri, and bur oak in southern Minnesota and Wisconsin. Mixtures of pine and oak also occur on these sites in Missouri and Lower Michigan.

These poor sites should probably be managed for pulpwood or other small products if markets exist. The best management for oak stands on the poorest sites may be no management. When they provide a commercial harvest, they should be harvested, but cultural work should be limited to that necessary to provide for adequate regeneration. Thinnings may be feasible in stands on sites in the upper part of the range. However, trees should be of merchantable size and the thinning operation should pay for itself.

Conversion of these sites to pine or managing them for pine-oak mixtures is often feasible, and should be done if the cost of conversion is not prohibitive (see "Conversion To Other Species", p. 10).

Rotation Length

D. Oaks are relatively long-lived trees and rotation can be long. In unthinned stands, individual tree growth is slow and dominant trees on site 55, at age 80, will average about 12 inches in diameter, while those on site 75 at age 80 will average about 18 inches in diameter.

Rotation lengths can be shortened if stands are thinned early and regularly. The rotation lengths and tree sizes recommended in table 2 assume thinnings will be started early and continued on a regular cycle over the rotation.

Table 2. — *Recommended rotation lengths and diameter for oak sawtimber*[1]

Site index class	Rotation length	Rotation diameter[2]
Feet	*Years*	*Inches*
75+	60-75	24-28
55-74	75-90	20-24
40-54	90-120	16-18

[1]Rotation lengths for pulpwood are about 1/2 to 2/3 of those for sawtimber.

[2]Average diameter of crop trees.

Controlling Stand Establishment

E. Two basic principles of reproducing oaks must be understood by silviculturists managing this type.

1. The newly reproduced stand will contain oaks proportion to the advance oak reproduction on the a before the overstory is removed.

2. Advance oak reproduction must be relatively lar with a well established root system, in order to comp successfully with other woody vegetation in the n stand.

Before a final harvest cut is made, the oak adva reproduction should be inventoried to determine if i adequate to ensure a dominant oak component in new stand. (See Appendix IV, "Evaluating the Adequ of Oak Advance Reproduction".) If the minim standards of this guide are met, the old stand can removed. Clearcutting is the recommended silvicultu system. After the merchantable timber is harvested, remaining trees larger than about 2 inches d.b.h. about 20 to 25 feet tall) should be removed. Desira oaks should be cut and allowed to sprout. Species wanted in the next stand should be killed. This important because if left, many of these trees become wolf trees.

F. If the oak advance reproduction does not meet standards in the guide, harvest cutting should delayed. If oak advance reproduction is scarce or abs new seedlings will have to be established. There are known cultural techniques that result in new seedli being established. Some reduction of overstory den should help to stimulate seed production, but becaus the periodicity of seed crops the time required establish enough new seedlings for adequate stockin likely to be relatively long.

Site preparation by soil scarification has not pro beneficial in establishing new oak seedlings. Even wh many new seedlings are initially found on scarified ar after a few years there are just as many present unscarified as on scarified areas.

In areas of known heavy deer populations and se browsing, or high populations of acorn-consuming w life, it will be impossible to establish natural regeneration unless measures are taken to control consuming animals. If control is not feasible, seedlings can be planted, but they will have to protected from deer.

Where advance reproduction is scarce or absent, seedlings can be planted under an overstory and allo to develop as advance reproduction. This practice not been tried and proven and its ultimate succes failure is unknown. The overstory should be mainta at about 60 percent stocking and if competition fro

sting understory will impair the growth of the planted dlings, its density should be reduced. Seedlings should planted at the rate of 500 to 600 per acre. Spacing be irregular and seedlings should not be planted se to large overstory trees. As with natural reproduc- n, the planted seedlings must be allowed to reach the imimum size necessary before the overstory is finally oved.

lant the largest oak seedlings available. Seedlings uld be at least 1/4-inch in diameter at the root collar. not be afraid to cull the smaller ones. The larger dlings have a much better potential because of their er root systems. Size is critical in the root system's ity to support vigorous shoot growth after harvest ing.

anting oaks after clearcutting has generally been tisfactory because the planted seedlings do not grow enough to compete with the new sprouts.

nce new seedlings are established, or if advance oduction is present in sufficient numbers but below minimum size, they must be allowed to grow in the erstory until they reach the minimum size. Oak nce reproduction grows slowly and the development od may be 10 to 20 years or longer. Cultural niques to enhance oak advance reproduction growth yet to be developed. Maintaining the overstory at o 60 percent stocking should help. And, if there is nderstory of competing woody stems present, its ity should probably be reduced by killing the anted stems with herbicides.

Controlling Composition

The composition of oak-hickory stands can be ed to some degree at any time before a stand hes large pole or small sawtimber size. However, the time to control composition is when regeneration is established. Oaks will be present in new stands in ortion to their occurrence in the advance reproduc- And, the composition of the advance reproduction ten unrelated to that of the overstory. Although one species may predominate in the overstory, a rent oak may prevail in the understory.

reasing the amount of one oak species relative to rs is difficult. If advance reproduction is well lished and adequate for several species, the less able species can be removed from the advance oduction by selective treatment with herbicides. If nce reproduction is scarce and the overstory is well ked, the species not wanted can be removed from the overstory so no seed of that species will be available. Another alternative is to underplant the wanted species, and at the same time remove the unwanted species from the overstory. In any situation where composition control in the advance reproduction is needed or wanted, the principles applicable to controlling stand establishment must be followed (see p. 6).

Weedings or cleanings may be necessary to control composition and maintain oaks in the new stands. They should be made no later than 10 years after harvest cutting, particularly if oak advance reproduction was barely adequate or stump sprouts were depended on to furnish the oak component of the new stands.

When these weedings or cleanings are made, reduce stump sprout clumps to one or two stems, and release the fastest growing oak stems. Do not attempt to eliminate all undesirable stems. Select potential crop trees on a spacing of about 15 feet and release only those that need it. Generally, dominant and codominant trees should be selected for crop trees. However, some of the better intermediates may be released if necessary to maintain an adequate stocking of oaks.

Controlling Growth

H. Total growth or production of wood in oak stands will be about the same over a wide range of stocking, provided there are enough trees in the stand to fully utilize the site. However, individual tree growth will be greatest near the lower limit of stocking that fully utilizes the site. Although total growth cannot be increased, regulation of stocking by thinning results in growing merchantable products quicker, increased product yields, and shorter rotations.

Thinnings should be started as early in the life of a stand as possible in order to realize the full potential yields of the site (table 3). When thinnings are started at age 10 to 20, and followed by periodic thinnings at about 10-year intervals, the time required to grow trees to a given diameter can be greatly reduced and the greatest yield obtained (see Appendix II, tables 11-19). The first thinning in these young stands and possibly the second may not yield commercial products unless a market for small roundwood exists. If precommercial thinnings are not feasible, the latest effective first thinning age for rapid growth response is 40 or 50 years. Previously unthinned stands older than 50 years can and probably should be thinned, especially on good sites. Although residual trees are not likely to respond very well, merchantable products can be recovered from trees

Table 3. – *A comparison of yields per acre at age 60 when thinning is begun at different ages; thinning interval 10 years (Gingrich 1971)*

Yields at age 60	Age of stand at time of first thinning (years): 10	20	30	40	50	60
SITE 55						
Cubic feet	3,900	2,940	2,910	2,580	2,550	2,520
Cords	37.8	28.8	27.6	23.7	23.4	22.9
Board feet	8,340	4,680	3,360	2,700	1,500	900
SITE 65						
Cubic feet	4,860	4,040	3,750	3,270	3,270	3,300
Cords	44.1	35.4	34.5	30.6	31.2	30.8
Board feet	12,000	7,680	5,220	4,680	4,600 (7,000)*	5,160 (6,580)*
SITE 75						
Cubic feet	6,360	5,400	4,770	4,290	4,080	4,140
Cords	56.7	49.2	44.7	39.3	37.7	37.7
Board feet	18,840	14,100	10,080	9,000	7,800 (11,800)*	9,288 (10,850)*

*Board-foot yields at age 70.

about to die and the overall vigor and health of the remaining trees will improve.

Poor sites are the only exception to this. On poor sites the cost of precommercial thinnings probably cannot be recovered because of the long period of time these costs will have to be carried at compound interest.

In young stands of sapling or small pole (15 to 20 years old) size, the first thinning can be a crop tree release. For crop trees select only dominant or codominant trees on a 15- to 20-foot spacing, and release only those that need it. This spacing should provide acceptable stocking of crop trees by the time the trees average large enough for commercial thinnings.

Thinnings cannot be continued indefinitely. Maintaining good growth on the trees left in the stand requires that they be spaced so the site is fully occupied and that the effect of a thinning is distributed throughout the stand. When the trees become large, removal of only a few trees does not benefit the entire stand, and may leave large holes in the canopy – a situation that should be avoided. In general, if a stand has been thinned regularly, stop thinning oaks at 60 to 70 years on average sites, and 50 to 60 years on good sites, or about three-fourths of rotation age.

Twenty to 30 years prior to the contemplated harvest age, managers should be establishing and developing oak advance reproduction to replace the current stand. Thus, some cultural measures may be required beyond the age when thinnings to maintain growth are stopped.

Stocking percent should be used as the measure of stand density to control thinning intensity (see Appendix III, "Evaluating Stand Density and Growing Stock Quality"). Generally oak stands should be thinned to leave residual stands at about 60 percent stocking. There are two exceptions to this general rule: in young stands less than 20 years old, and in stands 30 years and older.

In stands 20 years old or less, the first thinning m… reduce stocking to 50 percent. These young stands gr… rapidly and in 10 years they will again be approaching maximum stocking. In stands 30 years and older, the first thinning should reduce stocking to only 70 perce… Trees that have grown in stands near maximum stock… for 30 years or longer have relatively small crowns t… cannot quickly expand and occupy the available grow… space if thinned too heavily. Moreover, the residual tr… will develop excessive bole sprouts which reduce qual… A more gradual opening of these older stands will all… the crowns to expand gradually, utilize the increa… growing space more efficiently, and reduce bole spro… ing. The second and subsequent thinnings should t… reduce stocking to about 60 percent.

Thinning should generally be from below for a go… biological reason. Intermediate and suppressed trees h… very small crowns, are of low vigor, and respond v… slowly to release. However, dominant and codomin… trees are usually of high vigor, are the best quality tr… and respond to release with rapid growth. To thin … stands from above only lengthens rotations and low… the quality of the growing stock.

Leave the best trees spaced as uniformly as possible throughout the stand. In a first thinning at age 20 or later it will probably be impossible to remove all of the undesirable trees and still retain about 60 percent stocking and adequate spacing. Remove as many as possible in the first thinning and the remainder in the second and third thinnings.

Fully stocked, immature stands are prime candidates for thinning. In such stands, the size class that will form the main stand must be chosen and the trees in that size class managed to maturity. In some existing stands, two adjacent size classes (saplings-pole or poles-sawtimber) might have to be combined in order to form a main stand with adequate stocking.

If the main stand is saplings or poles, thinnings should not be delayed. Reduce stocking to not less than B level (see Appendix III, fig. 7) and plan to make additional thinnings at about 10-year intervals.

If the main stand is sawtimber, the intensity of thinning depends on how well the stand is stocked, how close to maturity the stand is, and on the quality of the growing stock.

If the basal area of acceptable growing stock is above C level (see Appendix III, fig. 7), the stand is worth managing, but if it is below B level it will be several years before the good trees will fully occupy the site. If acceptable growing stock is below C level, the stand cannot be saved without great waste of time and growing space and should be regenerated as soon as adequate advance reproduction exists.

When no single size class contains more than 50 percent of the total basal area, combine two adjacent size classes for a manageable stand. In such cases the recommendations for the size class with the most basal area should generally be followed when making intermediate cuts. There are probably exceptions to this general rule, and good professional judgment must be used to make the final decision.

If the majority of the trees are 80 percent or greater of the desired rotation diameter for the site (table 2), whether to cut or not depends on stocking and the adequacy of the oak advance reproduction present. If stocking is 80 percent or more, a light thinning can be made and is especially desirable if oak advance reproduction is scarce or small. However, in previously unthinned stands, DO NOT reduce stocking below 70 to 75 percent and do not make large holes in the stand. DO NOT be tempted to make a cut in this type of stand merely because it contains good volumes of desirable trees or to get volume to satisfy cutting goals. Any cutting should be designed more to enhance the establishment or development of advance reproduction rather than growth. Cutting should be restricted to the poorest trees, and primarily the lower crown classes.

M. In stands 60 to 80 percent stocked, wait. These stands will usually have a fairly dense understory. If there is not much oak advance reproduction, some understory control is probably needed, but further reduction of the overstory is probably not necessary or desirable because not enough trees can be removed to benefit the entire stand.

N. If the majority of trees are less than 80 percent of the desired size for the site, the stand should be thinned unless the initial stocking is not much above B level. If the stand shows no evidence of cutting 10 to 20 years previously, do not reduce stocking below 70 percent and take note of oak advance reproduction adequacy. If the stand was cut 10 to 20 years previously, it can be thinned to B-level stocking but heed the warnings in section L. If initial stocking is not much above B level, do nothing unless oak advance reproduction is scarce. In any event, cutting should be light and designed more to increase oak advance reproduction than promote growth of the overstory trees.

O. Sawtimber stands that are understocked (below B level) or of poor quality should be rehabilitated or regenerated as soon as possible. Such stands will likely contain heavy understories, and should be regenerated immediately if oak advance reproduction is adequate. If not, measures must be taken to develop it.

MIXTURES OF OAKS AND OTHER SPECIES

Harvesting of existing oak stands in the "Driftless Area" of Wisconsin, Minnesota, Iowa, Lower Michigan, southern Illinois, and southern Indiana often results in the new stands of mixed composition. If oaks are few in number but well distributed in these new reproduction stands, it may be possible to create a stand with a good oak component by the time it reaches sawtimber size. To do this will require early weeding – possibly as early as age 5 – and careful attention to the oaks that are present.

Regulating stocking in mixed stands will depend primarily on the proportion of oaks in them. In the northern part of the north-central region, when oaks comprise two-thirds or more of the stand basal area at about age 20, the recommendations in this handbook should be followed. If oaks account for one-third or less of the basal area, use the recommendations in the handbook for northern hardwoods (Tubbs 1977). For those stands composed about equally of oaks and other hardwoods, there is no good information on which to base stocking. Thinnings in such stands should favor the best quality, fastest growing trees. Stocking levels should probably be intermediate between those for oaks and those for northern hardwoods.

In the southern part of the region, except in the Ozarks area, stocking in stands containing 50 percent or more of the basal area in oaks at about age 30 can probably be regulated according to the guidelines in this handbook. If stands contain more than 50 percent yellow-poplar or other intolerants, a somewhat higher stocking percent than shown in figure 7 (Appendix III) will be required, but how much higher is not accurately known. However, at a given average stand diameter, increasing the figure values by 20 percent appears to be a reasonable compromise.

Q. In mixed oak and pine stands there is no information available to guide regulation of stocking. When thinnings are made in such stands, they should provide adequate growing space for the best trees while maintaining adequate stocking to fully utilize the site. The pines will generally produce more and higher quality timber than oaks and should be favored as much as possible.

Conversion to Other Species

Consider converting existing oak stands to other species in the following three situations.

R. The first is where the ecological trends clearly indicate the replacement of oaks with more mesic species on good sites. This occurs in parts of Lower Michigan, Minnesota, Wisconsin, and northeastern Iowa where species such as white ash, American basswood, and sugar maple grow well.

These stands may be converted immediately if a seed source of desirable nonoak species is present. There will usually be an understory composed primarily of these species. Removal of the oak overstory may be by shelterwood (Tubbs 1977), or by clearcutting if the understory is well developed.

If a seed source of desirable nonoak species is limit or lacking, planting will be required; simply removi the oak overstory will lead to the development of stand composed of undesirable nonoak species. Wh ash, sugar maple, or other suitable species should interplanted. The seedlings planted should be large a competing vegetation may need to be controlled. Her cides should be applied as broadcast foliage spray bef harvest cutting and planting, or as selective st treatments at the time of planting (see Pesticide P cautionary Statement, Appendix V).

S. The second is in southern Illinois, southern India and parts of Lower Michigan, where oaks will be larg replaced by yellow-poplar, white ash, and other m mesic species as existing oak stands on good sites harvested. These species are generally minor compone of existing stands and can be converted simply clearcutting the mature stand. There may also be enou oaks present in new stands to form a manageable mix oak-other hardwood stand.

T. The third situation where conversion should considered is on poor sites in locations where shortle red, eastern white, and jack pines occur naturally. Th sites will produce higher timber yields if converted pine, and unless there is reason to retain oaks on th for purposes other than timber production, they sho be converted as soon as possible.

In the southern part of the region, conversion sho be to shortleaf pine. Site preparation is required seedbeds and to control hardwood competition. P scribed burning or bulldozing results in satisfact seedbeds. Bulldozing results in better hardwood cont than prescribed burning, but should be restricted to le areas or to gentle slopes where excessive erosion will be a problem. Shortleaf pine can be either direct see using 1/2 to 3/4 pound of repellent-treated seed acre, or planting 1-0 seedlings at a rate of 500 to 7 trees per acre.

To maintain pure seeded or planted shortleaf p stands, they may have to be released from hardw competition 2 to 4 years after establishment. Howe if the competing hardwoods are desirable oaks, consi managing the stands as mixtures.

In the northern part of the north central States, m oak stands are growing on low sites that were form in pine; these sites should be relatively easy to conv back to pine. Red pine is the first choice. If blister rus not a factor, eastern white pine is also satisfactory. J pine can also be used, particularly for pulpwood, and

ery poor sites. To establish these northern pines use the uidelines in the jack pine and red pine handbooks 3enzie 1977a, 1977b).

Damaging Agents

re

Fire has had an important role in the establishment of kisting oak stands throughout the north central States. he recurrent fires that followed cutting of the original mber stands all but eliminated the less fire-resistant ecies. The oaks were able to survive because of their bility to sprout repeatedly. With the advent of fire otection and control of widespread burning, the esent oak stands developed.

Although fire has been a prime factor in the development of the present oak stands, its use as a silvicultural ol for regenerating oak cannot be recommended now. here it has been tried, it has not been successful in oducing the desired results.

Oaks are susceptible to damage by fire at all stages uring a rotation. The primary damage is the killing of e cambial tissue at the base of the tree and the bsequent decay of the wood. Many of the cull trees in esent oak stands are cull because of fire. For this ason, fire should generally be excluded from oak ands.

rought

Drought is one of the most seriously damaging agents oak stands. Twelve- to 16-week periods without infall, especially if recurring in successive years, can verely affect oaks for several years. Growth is reduced d weakened trees are often attacked by insects and ot rot.

The effects of severe drought are less in thinned stands an in dense stands, however. Thinned stands are more sistant because the trees have better vigor, and even ough growth will be lowered, trees can often withstand the attack by secondary agents.

isease

Heartwood decay by wood rotting fungi is one of the ost serious diseases of oaks. Although trees are seldom lled, decay often renders the entire stem unusable for nber products. The primary entry points for decay ngi are fire scars and dead branch stubs. There are any species of wood rotting fungi, but the most iportant ones are *Poria andersonii, Stereum gaustapatum, Stereum frustulatum, Hericium* spp., *Polyporus compactus, Poria cocos, Irpex molli,* and *Polyporus sulphureus.*

Losses from these organisms can be reduced by fire protection and through silvicultural practices. In oak sprout clumps the upper sprouts should be thinned out before heartwood begins to form and the sprouts of lowest origin on the stump retained. In thinnings, one or more sprouts separated from a companion sprout by a low U-shaped crotch can be safely removed. However, sprouts that form a V-shaped crotch should either be left alone or the entire clump cut. Stand density in young stands should be high enough to shade out the lower branches while they are small.

Mortality from oak wilt, a vascular fungus disease, may be locally severe. This disease kills species of both the red and white oak groups. Red oaks usually die within a few weeks after the symptoms first become evident. White oaks are more resistant to the disease because of the presence of tyloses in the vessels and trees usually die over a 2- to 3-year period. The disease spreads from tree to tree through root grafts and is also spread by insects. There are no known control measures that are completely effective.

Less serious diseases that attack oaks are anthracnose, leaf blister, and the canker diseases.

Insects

Many insects attack the oaks. Severe damage and degrade to lumber are caused by the carpenterworm, the white oak borer, the red oak borer, and Columbian timber beetle. Important insects that feed on the leaves include the variable oak leaf caterpillar, gypsy moth, oak leaf roller, oak leaf tier, forest tent caterpillar, and the orange-striped oakworm. These insects are capable of completely defoliating oaks, sometimes over rather large areas. A single defoliation is not serious but may result in weakened trees and a loss of growth. Defoliation each year for 2 or 3 years or more can cause mortality that is sometimes widespread and severe. Volume losses can be high. Insects that attack acorns cause heavy losses and may even destroy the entire crop in years of low production. Acorn weevils are the most destructive of the acorn-attacking insects.

There are no practical insect control measures for use in oak stands. Chemicals can be used to control the defoliators if the cost can be justified (see Pesticide Precautionary Statement, Appendix V). Removal of the low vigor, defective trees during thinnings should help reduce damage from wood boring insects.

OTHER RESOURCE CONSIDERATIONS

Water

Silvicultural activities in oak forests will have little impact on water yields. Although an area that is clearcut for regeneration will yield more water for a few years, this yield gradually diminishes. Vegetation grows rapidly following clearcutting and after 5 to 10 years the water yield will be essentially the same as from a mature stand. Peak flows may be increased somewhat from clearcut areas, but this increase is usually of no practical significance and will not contribute to flooding. Thinnings will have a negligible effect on water yield so long as stands are maintained at least at B-level stocking.

Sedimentation resulting from cuttings will be minimal if proper precautions are taken. Water will not flow overland in clearcuts unless the forest floor has been scraped off or destroyed. Thus, disturbance of the forest floor should be kept as low as possible. Careful location, construction, and proper maintenance of roads and skid trails is necessary. Where site preparation for regeneration includes scarifying or burning for seedbeds, take extreme care in planning and executing these measures to avoid excessive overland water flow and erosion.

Where water yield is of primary importance such as on municipal watersheds, established principles of good watershed management must be followed. Timber yields will be of secondary importance.

Wildlife

Oak forests provide habitat for numerous wildlife species. The principal game species include white-tailed deer, turkey, fox, and gray squirrels, and in some areas ruffed grouse. Other important species include raccoon, opossum, red fox, bobcat, skunk, and a host of birds.

Creating and maintaining diverse vegetation is the key to providing a large variety of wildlife with suitable habitat. Regeneration clearcuts should be planned for a whole rotation and dispersed throughout a compartment or group of compartments to provide a well regulated range of age classes. This will result in several vegetation stages ranging from open, recently clearcut regeneration areas, through areas of saplings, poles, immature sawtimber, and mature sawtimber. Each of these stages contributes to the habitat requirements of different groups of wildlife species.

Even so, special measures to enhance the habitat f species with specific requirements may sometimes needed. Many of these measures will result in low timber yields, but to what extent is unknown. Duri thinning operations, a few defective trees can be left provide cavities or potential cavities for hole-nesti wildlife species. About 30 cavity-nesting bird speci inhabit oak forests. In addition to cavities, some of the birds need an open overstory and a well develop mid-story – conditions often found in old-growth overmature stands. Retaining selected stands beyond t normal rotation age will provide these conditions.

Leave dead snags standing in clearcut areas and kil unmerchantable trees during thinning operations inste of cutting them, so as to provide sites for hole-nesti species. This should have little or no effect on timb production.

One of the most important contributions to wildli from oak stands is mast, or acorns. Acorns are, course, vital for regenerating oak, and any measures th will increase or optimize acorn production in a particul stand will benefit both wildlife and timber productic In general, thinnings that increase tree growth will al stimulate acorn production. Maintaining 40 to percent of the area of each compartment in stands mast-bearing age will be optimum for wildlife. compartments that contain a relatively high proporti of poor sites that would produce more timber i converted to pine, this may mean foregoing conversi and the higher yields it would bring.

High populations of acorn-consuming wildlife can detrimental to establishing oak reproduction. Even good acorn years, essentially the entire crop may be lo in such areas. Acorns not damaged by insects will eaten by squirrels, turkey, deer, or other acorn co sumers, and thus not be available for reproducing t oaks.

Esthetics

Oak-hickory forests can be managed with a minimu of visual impact if operations are planned and execut carefully. Primarily, the cutover areas should appear ne and orderly. In travel zones stumps should be low a slash should be lopped. Logging roads and skid tra

ould be located and constructed to cause the least dscape disruption possible. Trash should not be owed to accumulate.

Clearcutting is the most unsightly of any silvicultural eration, but it need not be. It is very important to sign clearcuts to fit the topography and general dscape. They should not dominate the landscape, and they are large, they should be irregular in shape so that ly portions are visible from one observation point. ad snags may be objectionable in some instances, but 1 be left to provide sites for cavity-nesting birds. Occasionally small groups of trees can be left to add variety.

To maintain visually pleasing conditions around campgrounds, picnic areas, and other areas of high recreation use, the usual silvicultural practices have to be modified. Thinnings should be light and the slash lopped and scattered. Openings can be made for regeneration if they are kept small. Perpetuation of oaks will be difficult at best. Reproduction should be ensured by planting if necessary and care taken to develop the seedlings. Costs will be high but timber production is of secondary importance in these areas.

APPENDIX I

SITE INDEX CURVES AND TABLES

Table 4. – *Black and scarlet oak site index estimates by 2-foot height and 2-year age intervals*[1] *(McQuilkin 1974)*

Age :	Height (feet)																																								
(years):	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88
10		55	57	59	61	63	64	66	68	70	72																														
12			54	56	58	60	62	63	65	67	69	71																													
14				53	55	57	59	61	62	64	66	68	70	72	74																										
16					52	54	56	58	60	62	63	65	67	69	71	73	75																								
18						51	53	55	57	59	60	62	64	66	68	70	72	74	76	78																					
20							50	52	54	56	58	60	61	63	65	67	69	71	73	75	77	79																			
22								49	51	53	55	57	59	61	63	65	67	69	71	73	75	77																			
24									48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78																	
26										48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78																
28										45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	76																
30											45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77														
32												45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77													
34													45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77												
36													42	45	47	49	51	53	55	57	59.	61	63	65	67	69	71	73	75	78											
38														42	44	47	49	51	53	55	57	59	61	63	65	67	69	71	74	76	78										
40															42	44	47	49	51	53	55	57	59	61	63	65	67	70	72	74	76	78									
42																43	45	47	49	51	54	56	58	60	62	64	66	68	70	72	74	76	78	80							
44																	44	46	48	50	52	54	56	58	60	62	64	67	69	71	73	75	77	79	81						
46																	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81					
48																		43	45	47	49	51	53	55	57	59	61	64	66	68	70	72	74	76	78	80	82				
50																			44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82			
52																				45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81			
54																				44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	75	77	79	81		
56																				43	45	47	49	51	53	55	57	59	61	63	65	67	68	70	72	74	76	78	80		
58																					44	46	48	50	52	54	56	58	60	62	63	65	67	69	71	73	75	77	79	81	
60																					44	45	47	49	51	53	55	57	59	60	62	64	66	68	70	72	74	75	77	79	
62																					43	45	47	48	50	52	54	56	58	60	61	63	65	67	69	71	73	74	76	78	80
64																					42	44	46	48	50	51	53	55	57	59	61	62	64	66	68	70	71	73	75	77	79
66																						43	45	47	49	51	52	54	56	58	60	61	63	65	67	69	70	72	74	76	78
68																						43	45	46	48	50	52	53	55	57	59	61	62	64	66	68	69	71	73	75	76
70																						42	44	46	47	49	51	53	54	56	58	60	61	63	65	67	68	70	72	74	75
72																						42	44	46	47	49	51	52	54	56	57	59	61	62	64	66	68	69	71	73	74
74																							44	45	47	49	50	52	54	55	57	59	60	62	64	65	67	68	70	72	73
76																							43	45	47	48	50	52	53	55	56	58	60	61	63	64	66	68	69	71	73
78																								45	46	48	50	51	53	54	56	58	59	61	62	64	65	67	69	70	72
80																								45	46	48	49	51	52	54	55	57	59	60	62	63	65	66	68	69	71

[1]All height and age combinations in this table are within the range of the original black oak data; height and age combinations within the lines indicate the range of the original scarlet oak data.

Table 5. – *White oak site index estimates by 2-foot height and 2-year age intervals*[1] *(McQuilkin 1974)*

Age (years)	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92
0	46	49	52	54	57	60	62	65	68																																	
2	44	47	49	52	54	57	60	62	65	68																																
4		44	47	49	52	54	57	59	62	64	67	69																														
6			44	47	49	52	54	56	59	61	64	66	68	71																												
8				44	47	49	51	54	56	58	61	63	65	68	70																											
0					44	46	48	51	53	55	57	60	62	64	66	69																										
2					42	44	46	48	51	53	55	57	60	62	64	66	69	71																								
4						42	44	46	48	51	53	55	57	59	62	64	66	68	71																							
6							42	44	46	48	51	53	55	57	59	62	64	66	68	70																						
8								42	44	46	48	50	53	55	57	59	61	64	66	68	70																					
0									42	44	46	48	50	52	55	57	59	61	63	66	68	70																				
2									40	42	44	46	48	51	53	55	57	59	61	64	66	68	70																			
4										40	42	44	46	49	51	53	55	57	59	62	64	66	68	70																		
6											40	42	45	47	49	51	53	55	57	60	62	64	66	68	70																	
8												40	43	45	47	49	51	53	55	57	60	62	64	66	68	70																
0													41	43	45	47	49	51	53	55	58	60	62	64	66	68	70															
2													39	41	44	46	48	50	52	54	56	58	60	62	64	66	68	71														
4														40	42	44	46	48	50	52	54	57	59	61	63	65	67	69	71													
6														39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71												
8															39	41	43	45	47	49	52	54	56	58	60	62	64	66	68	70												
0															38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70											
2																39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71										
4																	40	42	44	46	48	50	52	54	56	58	60	62	63	65	67	69	71									
6																	39	41	43	45	47	49	51	53	55	56	58	60	62	64	66	68	70									
8																		40	42	44	46	48	50	51	53	55	57	59	61	63	65	67	68	70								
0																		39	41	43	45	47	48	50	52	54	56	58	60	61	63	65	67	69	71							
2																			41	42	44	46	48	49	51	53	55	57	58	60	62	64	66	67	69	71						
4																			40	42	43	45	47	49	50	52	54	56	57	59	61	62	64	66	68	69	71					
6																			39	41	43	44	46	48	49	51	53	54	56	58	59	61	63	64	66	68	70					
8																			39	40	42	44	45	47	49	50	52	54	55	57	58	60	61	63	65	66	68	69				
0																				40	41	43	45	46	48	49	51	52	54	55	57	58	60	62	64	65	66	68	69			
2																				39	41	42	44	46	47	49	50	52	53	55	56	58	59	61	63	64	66	67	69	70		
4																				39	40	42	43	45	47	48	50	51	53	54	56	57	59	61	62	64	65	67	68	70		
6																					40	41	43	45	46	48	49	51	52	54	55	57	58	60	62	63	65	66	68	69	71	
8																					39	41	42	44	46	47	49	50	52	53	55	56	58	59	61	63	64	66	67	69	70	
0																					39	40	42	43	45	47	48	50	51	53	54	56	57	59	60	62	64	65	67	68	70	71

[1]All height and age combinations to the left of the line are within the range of the original data; combinations to the right of the line are extrapolations.

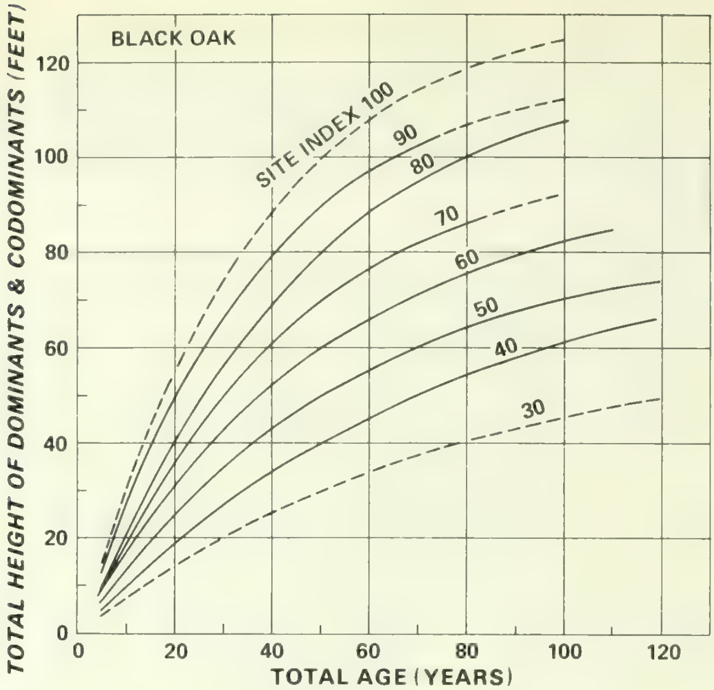

Figure 1. – *Site index curves for black oak in the Central States. These curves are based on stem analyses of 300 dominant and codominant black oaks growing on 120 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Indiana, southern Illinois, and southern Missouri (Carmean 1971).*

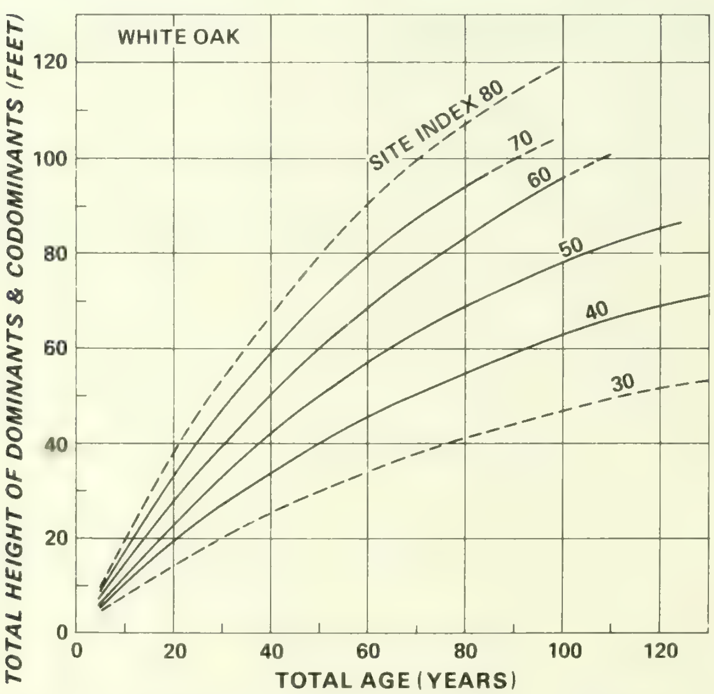

Figure 2. – *Site index curves for white oak in the Central States. These curves are based on stem analyses of 112 dominant and codominant white oaks growing on 41 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Indiana, southern Illinois, and southern Missouri (Carmean 1971).*

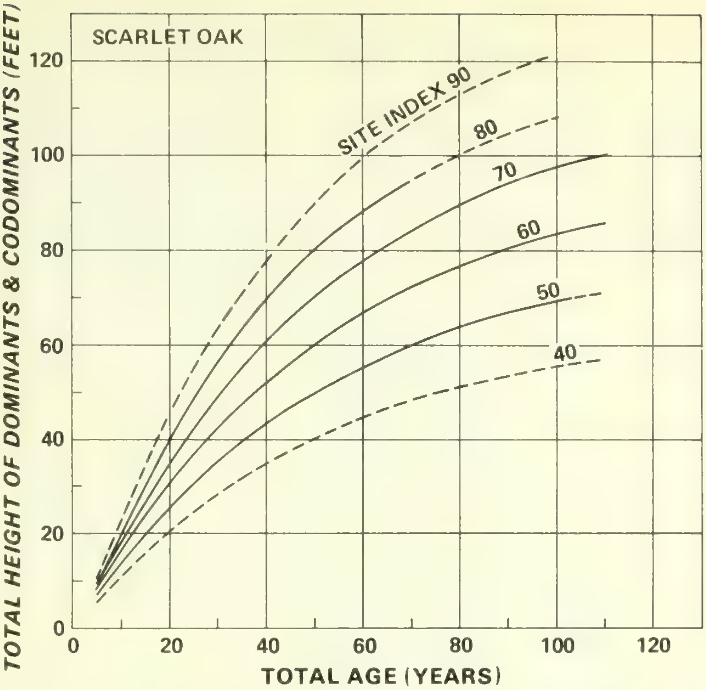

Figure 3. — *Site index curves for scarlet oak in the Central States. These curves are based on stem analyses of 88 dominant and codominant scarlet oaks growing on 25 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Illinois, and southern Missouri (Carmean 1971).*

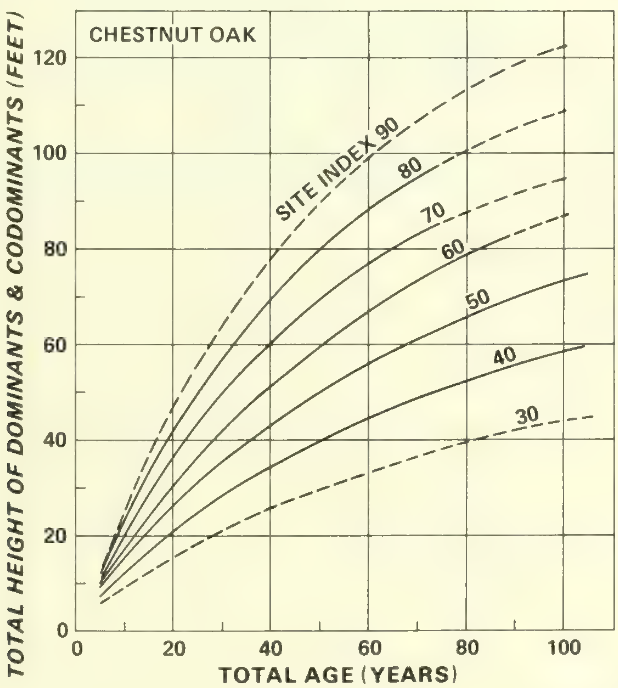

Figure 4. — *Site index curves for chestnut oak in the Central States. These curves are based on stem analyses of 59 dominant and codominant chestnut oaks growing on 18 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, and southern Indiana (Carmean 1971).*

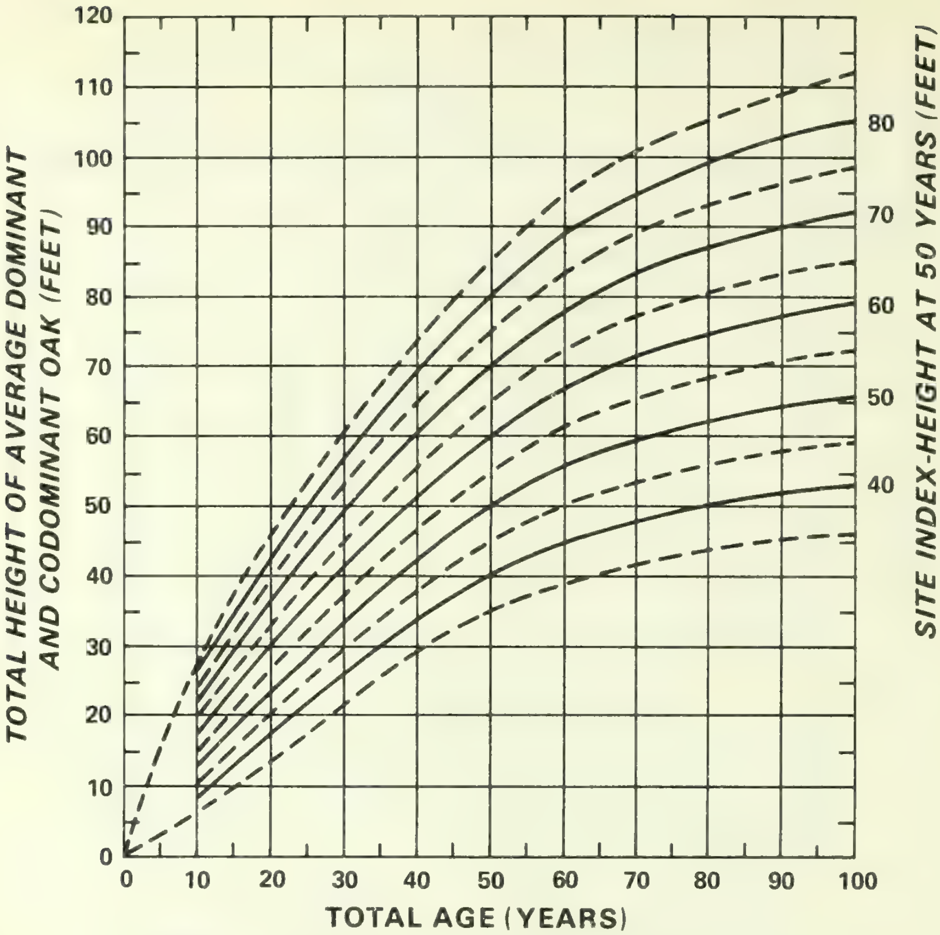

Figure 5. – *Site index curves for upland oak (Schnur 1937).*

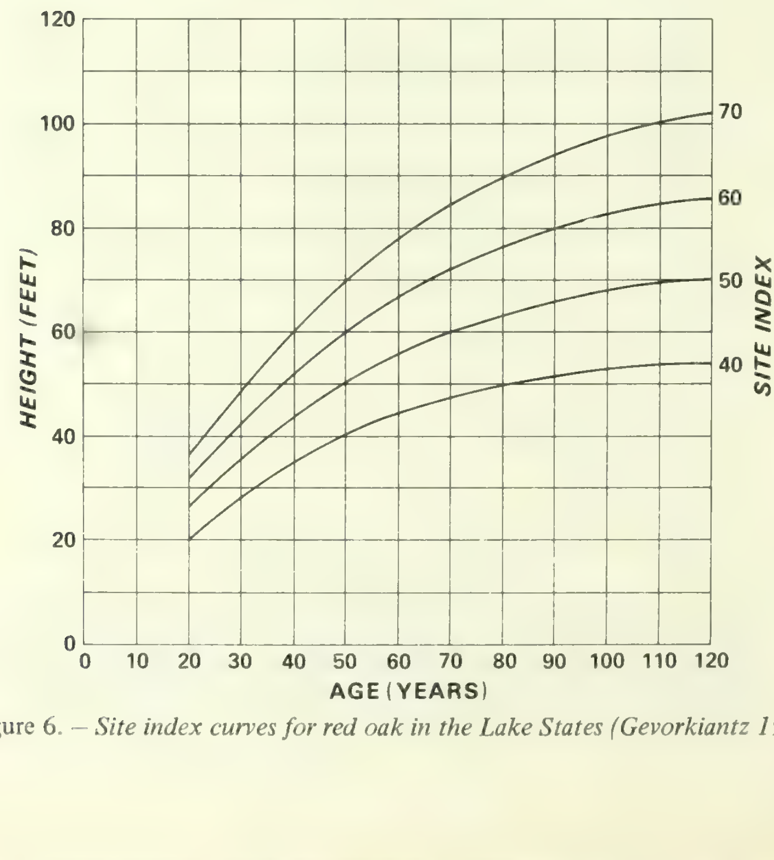

Figure 6. – *Site index curves for red oak in the Lake States (Gevorkiantz 1957).*

Table 6. – *Soil and topographic features affecting site productivity of oak forests in the Lake States (Arend and Scholz 1969)*

	Site index and growth potential at age 80[1]				Soil features and corresponding topographic features[2]	
…te …lity	Site index	Number 16-foot logs	Mean annual growth per tree	Periodic annual growth per acre	Soil	Topography
			Cu. ft.	*Bd. ft.*		
…d	70+	2½+	0.4-0.6	200-300	A. Deep, moderately and well-drained silts, loams, and clays where soil depth is 3 feet or more to parent rock; sands where water table is within 4 to 10 feet of the surface.	A. On relatively flat topography, broad ridges, lower slopes, bottoms and valley coves; all north and east slopes where gradients are less than 20 percent; middle north and east slopes where gradients range from 20 to 35 percent.
…ium	55-65	1½-2½	.3- .4	100-200	A. Moderately deep (20 to 36 inches) silts, loams, and clays, or deep sands, with fine-textured bands in subsoil 2 to 6 inches in thickness at depths less than 60 inches. B. Deep sands. C. Deep silts and loams.	A. On relatively flat land, upper and middle north and east slopes where gradients are less than 20 percent; middle north and east slopes where gradients range from 20 to 35 percent. B. On lower slopes in rolling topography. C. On upper and middle south and west slopes where gradients are less than 20 percent.
…r	40-55	½-1½	.1- .2	Less than 100	A. All shallow soils less than 20 inches in depth and deep porous sands. B. All soils. C. All soils.	A. On flat topography. B. On narrow ridges and upper slopes in hilly topography. C. On middle south and west slopes where gradients exceed 20 percent.

[1]Measurements from dominant trees (red oak group) in unmanaged stands.
[2]Does not apply to prairie soils and loessial deposits.

Table 7. — *Site characteristics to be considered in classifying the productivity of upland sites in southern Michigan for black and red oaks* (Gysel and Arend 1952)*

Texture of subsoil	Position of the moist layers in the substrata	General topography	Position on slope	Site class
Fine	High†	Flat		VERY GOOD
	High†	Rolling	Upper	GOOD
			Middle	GOOD
			Lower	GOOD
			Bottom	VERY GOOD
	High†	Hilly	Upper	MEDIUM
			Middle	GOOD
			Lower	GOOD
Medium	Low	Flat		MEDIUM
	Low	Rolling	Upper	MEDIUM
			Middle	MEDIUM
			Lower	GOOD
			Bottom	VERY GOOD
	Low	Hilly	Upper	POOR
			Middle	MEDIUM
			Lower	GOOD
	High	Flat		GOOD
	High	Rolling	Middle	GOOD
Coarse	Low	Flat		VERY POOR
	Low	Rolling	Upper	VERY POOR
			Middle	POOR
			Lower	MEDIUM
			Bottom	GOOD
	Low	Hilly	Upper	VERY POOR
			Middle	POOR
			Lower	GOOD
	High	Flat		GOOD
	High	Rolling	Middle	GOOD

*The combinations of site characteristics listed describe the most common sites on which oak was found in southern Michigan during this study.

†"High" for the fine-textured subsoil class refers to varying amounts of clay.

Table 8. – *Oak site index and soil characteristics in northeastern Iowa (Einspahr and McComb 1951)*

Soil Series	Textural composition A	Textural composition B	Horizon thickness A	Horizon thickness B	Horizon thickness Total	Permeability sub-soil	Natural internal aeration	Moisture condition due to topographical position	Percent slope	Site index
			Inches							
haseburg- udson	Silt loam	Silt clay loam	14	16	D[1]	Moderate	Good	Very good	4	64
ayette	Silt loam	Heavy silt loam	10	16	D[1]	Moderate	Good	Fair	15	60
andahl	Silt loam to sandy loam varying amounts of rock fragments.		14	12	D[1]	Moderate	Good	Good	25	57
ubuque	Silt loam	Heavy silt loam	10	16	30	Moderate	Good	Fair	18	55
5	Clay loam to sandy loam varying amounts of rock fragments.		--	--	18	Moderate	Good	Good	10	52
eep stony aspect	Clay loam to sandy loam varying amounts of rock fragments.		--	--	--	Rapid	Good	Poor to good	40	52
elsea	Loamy sand to sand	--	--	--	D[1]	Very rapid	Good	Fair	10	44
eep stony aspect	Clay loam to sandy loam varying amounts of rock fragments.		--	--	5	Rapid	Good	Very poor to fair	40	37
ingle	Clay loam	Heavy clay	12	15	12	Very slow	Very poor	Fair	1	36
gn	Silt clay loam	Clay loam	--	--	8	Rapid	Good	Poor	8	33

[1]Greater than 36 inches.

Table 9. – *Predicted site index for white oak in southern Indiana (Hannah 1968)*

Position	Clay content of the lower subsoil horizon (B_2) (in percent)	A_1- and A_2-horizon thickness--inches: 2.0-4.0		4.1-6.0		6.1-8.0		8.1-10.0	
idges	Less than 40	51		57		64		73	
	40-60	44		50		56		63	
	More than 60	38		43		48		55	
		North	South	North	South	North	South	North	South
pper slopes 2-50	Less than 40	61	55	66	61	72	67	78	75
ercent of distance	40-60	55	48	60	53	65	59	71	65
rom ridge	More than 60	50	42	54	47	59	52	65	58
ower slopes 51-99	Less than 40	66	60	71	65	75	70	80	76
ercent of distance	40-60	60	53	64	57	68	62	73	66
rom ridge	More than 60	55	46	58	50	62	54	66	59
ottoms	Less than 40	73		77		80		84	
	40-60	68		71		74		77	
	More than 60	63		66		69		72	

Aspect: North slopes include azimuths from 315 to 135 degrees and south slopes include azimuths from 136 to 314 degrees.

Slope shape: All site-index values are for linear-shaped slopes. For concave-shaped slopes add 2 feet; for convex-haped slopes substract 2 feet.

Stone content: All site-index values are for relatively stone-free soils (0 to 30 percent stone in the B_2 horizon); for ony soils (31 to 60 percent stone in B_2) substract 2 feet; for very stony soils (more than 60 percent stond in B_2) substract feet.

Texture of the B_3 horizon: Site-index values in the table are for conditions where all subsoil horizons have the same eneral texture. Four feet should be subtracted from the values for subsoil with less than 40 percent clay if the B_2 of this il is underlain with a B_3, B_x, or C horizon having 40 to 60 percent clay. Four feet should be substracted from the values r subsoils with 40 to 60 percent clay if the B_2 of this soil is underlain by a B_3, B_x, or C horizon with more than 60 rcent clay.

Silt content: All site-index values are for soils with more than 25 percent silt in the B_1 horizon. For soils with less an 25 percent silt substract 4 feet from the indicated site-index values.

Table 10. – *Predicted site index for black oak in southern Indiana (Hannah 1968)*

Position	Depth of surface soil (A_1 + A_2 horizons--inches)						
	Less than 4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0	8.1-9.0	More than 9.0
Ridges	48	54	60	66	72	79	87
Upper slopes 1-25 percent of distance from ridge	51	56	62	68	74	80	87
Upper midslopes 26-50 percent of distance from ridge	56	62	66	72	77	82	88
Lower midslopes 51-75 percent of distance from ridge	62	67	72	76	80	84	89
Lower slopes 76-99 percent of distance from ridge	69	74	78	80	84	87	90
Bottoms	73	77	80	83	86	88	91

Stone content: All site-index values are for relatively stone-free soils (0 to 30 percent stone in B_2 horizon); for stony soils (31 to 60 percent stone in B_2), and very stony soils (more than 60 percent stone in B_2), the following substractions should be made:

Site index	Stony soil	Site index	Very stony soils
<60	-2	<60	-4
61-90	-3	61-75	-5
>90	-4	76-87	-6
		>87	-7

Subsoil texture: All site-index values are for soils having less than 40 percent clay in the subsoil (loams, clay loams, silty or sandy clay loams, and silt loams). For soils with heavier subsoil textures (more than 40 percent clay), the following substractions are needed:

Site index	Upper subsoil (B_2 horizon) has less than 40 percent clay; lower subsoil (B_3, B_x, or C horizon) has more than 40 percent clay	Site index	All subsoil horizons have more than 40 percent clay
	(Reduction)		(Reduction)
<52	-2	<57	-4
53-73	-3	58-69	-5
>74	-4	70-80	-6
		>80	-7

Texture of the B_3 horizon: Site-index values are for conditions where the B_2 horizon and those underlying it have the same general texture. Subtract 4 feet if a B_2 horizon with less than 40 percent clay is underlain by a B_3, B_x, or C horizon with 40 to 60 percent clay. Subtract 4 feet if a B_2 horizon with 40 to 60 percent clay is underlain by a B_3, B_x, or C horizon with more than 60 percent clay.

APPENDIX II

YIELD TABLES

Table 11. *Yields per acre for upland oak; no thinning (Gingrich 1971)*

Age	Basal area	Trees	Average tree diameter[1]	Yields		
Years	*Square feet*	*No.*	*Inches*	*Cubic feet*	*Cords*	*Board feet*
SITE INDEX 55						
20	55	2,500	2.0	60	0.6	--
30	75	1,260	3.3	583	5.3	--
40	87	790	4.5	1,320	12.1	--
50	97	480	6.1	2,150	19.7	400
60	104	357	7.3	2,520	22.9	900
70	108	295	8.2	2,730	24.4	2,800
80	112	242	9.2	2,880	25.6	5,400
SITE INDEX 65						
20	59	1,880	2.4	178	1.6	--
30	81	930	4.0	1,200	10.6	--
40	96	505	5.9	1,840	18.2	440
50	105	342	7.5	2,800	26.9	2,150
60	111	262	8.8	3,300	30.8	5,160
70	115	215	9.9	3,700	33.3	7,200
80	117	187	10.7	3,950	35.6	8,200
SITE INDEX 75						
20	70	1,425	3.0	694	6.4	--
30	89	680	4.9	1,670	16.7	--
40	101	400	6.8	2,440	23.7	1,380
50	110	279	8.5	3,315	30.1	4,100
60	114	222	9.7	4,140	37.7	9,288
70	117	187	10.7	4,760	43.0	11,200
80	120	166	11.5	5,160	46.5	12,500

[1]The diameter of the tree of average basal area.

Table 12. – *Yields per acre for upland oak; first thinning at age 10 (Gingrich 1971)*

Age	Residual stand					Cut stand				Cumulative total yields (cut stand plus residual stand)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
Years	*Square feet*	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
SITE INDEX 55												
10	20	1.9	--	--	--	--	--	--	--	--	--	--
20	48	4.1	515	5.0	--	7	25	--	--	540	5.0	--
30	58	5.9	1,190	9.9	240	20	345	4.2	--	1,560	14.1	240
40	64	8.0	1,640	15.0	1,560	19	350	3.6	160	2,360	22.8	1,720
50	71	10.6	1,990	18.3	3,800	16	415	4.4	590	3,125	30.5	4,550
60	75	13.0	2,280	20.7	6,540	16	485	4.9	1,050	3,900	37.8	8,340
SITE INDEX 65												
10	23	2.1	--	--	--	--	--	--	--	--	--	--
20	51	4.5	775	6.8	--	8	125	1.2	--	900	8.0	--
30	59	6.4	1,445	13.1	540	25	370	3.8	--	1,940	18.1	540
40	66	8.6	1,920	18.0	2,280	21	465	3.8	280	2,880	26.8	2,560
50	72	11.0	2,340	21.8	5,250	19	575	5.2	970	3,875	35.8	6,500
60	76	13.7	2,655	24.3	8,940	18	670	5.8	1,810	4,860	44.1	12,000
SITE INDEX 75												
10	25	2.5	--	--	--	--	--	--	--	--	--	--
20	55	5.4	1,060	9.6	--	12	200	1.6	--	1,260	11.2	--
30	62	7.4	1,920	17.5	1,380	30	520	5.2	60	2,640	24.3	1,440
40	71	10.5	2,550	23.0	4,840	22	610	5.6	500	3,880	35.4	5,400
50	75	13.2	3,025	26.8	10,300	22	745	6.8	1,540	5,100	46.0	12,400
60	78	15.5	3,360	29.7	13,200	21	925	7.8	3,540	6,360	56.7	18,840

Table 13. – *Yields per acre for upland oak; first thinning at age 20 (Gingrich 1971)*

SITE INDEX 55

Age	Residual stand: Basal area	Residual stand: Average tree diameter	Residual stand: Yield			Cut stand: Basal area	Cut stand: Yield			Cumulative total yields (cut stand plus residual stand)		
Years	*Square feet*	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
20	34	2.3	60	0.6	--	--	--	--	--	60	0.6	--
30	49	4.2	600	5.1	--	15	--	0.9	--	600	6.0	--
40	58	6.1	1,220	12.2	880	16	300	2.9	--	1,520	16.0	880
50	66	8.6	1,750	16.0	2,350	15	300	3.2	150	2,350	23.0	2,500
60	71	10.6	1,980	18.6	3,960	15	360	3.2	570	2,940	28.8	4,680
70	74	12.1	2,170	20.0	5,810	14	370	3.8	820	3,500	34.0	7,350
SITE INDEX 65												
20	37	2.8	160	1.6	--	--	18	--	--	178	1.6	--
30	50	4.6	750	7.4	--	20	132	1.2	--	900	8.6	--
40	63	7.7	1,760	16.0	1,320	15	290	3.2	--	2,200	20.4	1,320
50	69	9.8	2,150	19.7	3,500	19	625	4.1	400	3,215	28.2	3,900
60	73	12.0	2,460	22.5	6,120	18	515	4.4	1,160	4,040	35.4	7,680
70	77	14.6	2,730	24.2	9,030	16	520	4.9	2,010	4,830	42.0	12,600
SITE INDEX 75												
20	46	3.6	476	4.4	--	--	218	2.0	--	694	6.4	--
30	57	5.6	1,275	13.0	--	26	307	3.6	--	1,800	18.6	--
40	66	8.4	2,140	19.8	2,160	21	535	4.8	240	3,200	30.2	2,400
50	71	10.8	2,600	24.7	6,450	21	665	5.4	1,160	4,325	40.5	7,850
60	76	13.4	3,060	28.5	10,680	19	615	4.9	2,020	5,400	49.2	14,100
70	79	16.3	3,465	31.5	13,720	19	635	5.2	2,740	6,440	57.4	19,880

Table 14. – *Yields per acre for upland oak; first thinning at age 30 (Gingrich 1971)*

SITE INDEX 55

Age	Residual stand: Basal area	Residual stand: Average tree diameter	Residual stand: Yield			Cut stand: Basal area	Cut stand: Yield			Cumulative total yields (cut stand plus residual stand)		
Years	*Square feet*	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
30	58	4.3	528	4.8	--	17	55	0.5	--	583	5.3	--
40	55	5.7	1,120	9.4	200	27	265	3.1	--	1,440	13.0	200
50	62	7.8	1,600	14.2	1,500	15	330	3.4	--	2,250	21.2	1,500
60	67	10.2	1,950	17.4	3,000	15	310	3.2	360	2,910	27.6	3,360
70	72	11.7	2,135	19.6	5,040	12	335	3.1	550	3,430	32.9	5,950
80	75	13.0	2,280	20.6	8,000	12	345	3.7	1,010	3,920	37.6	9,920
SITE INDEX 65												
30	62	4.9	1,120	9.6	--	20	80	1.0	--	1,200	10.6	--
40	60	6.6	1,520	13.6	640	29	400	3.8	--	2,000	18.4	640
50	67	9.0	2,000	18.5	2,450	18	470	4.2	--	2,950	27.5	2,450
60	72	11.2	2,370	21.5	4,620	17	430	3.9	600	3,750	34.5	5,220
70	76	13.7	2,660	23.8	8,320	16	440	3.9	1,510	4,480	40.6	10,430
80	78	16.1	2,880	24.8	10,900	16	460	4.0	2,510	5,160	45.6	15,520
SITE INDEX 75												
30	66	5.5	1,450	14.0	--	23	220	2.7	--	1,670	16.7	--
40	62	7.1	1,840	17.0	1,400	34	600	5.5	--	2,660	25.2	1,400
50	68	9.7	2,400	22.8	4,200	20	555	5.0	650	3,775	36.0	4,850
60	73	12.4	2,880	26.7	7,980	19	515	4.8	1,450	4,770	44.7	10,080
70	77	15.2	3,325	29.8	13,020	17	490	4.4	2,100	5,705	52.2	17,220
80	80	17.7	3,760	31.6	15,440	16	500	4.8	3,400	6,640	58.8	23,040

Table 15. – *Yields per acre for upland oak; first thinning at age 40 (Gingrich 1971)*

Age	Residual stand: Basal area	Residual stand: Average tree diameter	Residual stand: Yield			Cut stand: Basal area	Cut stand: Yield			Cumulative total yields (cut stand plus residual stand)		
ears	*Square feet*	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
	SITE INDEX 55											
0	63	5.0	1,140	10.5	--	24	180	1.6	--	1,320	12.1	--
0	62	7.4	1,538	13.0	900	23	282	3.4	--	2,000	18.0	900
0	67	9.1	1,830	15.6	2,430	15	288	3.1	270	2,580	23.7	2,700
0	72	11.0	2,065	18.6	4,445	12	300	2.7	465	3,115	29.4	5,180
0	74	12.7	2,240	21.6	6,880	12	350	2.8	865	3,640	35.2	8,480
0	76	13.8	2,430	24.8	9,180	9	355	3.0	1,100	4,185	41.4	11,880
	SITE INDEX 65											
0	69	6.5	1,600	15.9	440	27	240	2.3	--	1,840	18.2	440
0	66	8.5	1,910	17.7	1,800	28	410	4.0	200	2,560	24.0	2,000
0	70	10.4	2,200	20.7	4,200	18	400	3.6	280	3,270	30.6	4,680
0	74	12.4	2,485	23.1	7,210	16	420	3.7	710	3,955	36.7	8,400
0	77	14.5	2,720	24.8	8,960	15	410	4.0	1,050	4,600	42.4	11,200
0	79	16.5	2,925	26.6	10,710	13	460	4.0	1,630	5,265	48.2	14,580
	SITE INDEX 75											
0	73	7.4	2,130	20.2	1,380	28	300	3.0	--	2,440	23.2	1,380
0	68	9.6	2,390	21.8	3,450	31	635	6.2	300	3,325	31.0	3,750
0	73	11.6	2,730	24.9	7,680	19	625	5.2	1,020	4,290	39.3	9,000
0	76	13.8	3,115	28.0	11,200	19	610	4.8	1,620	5,285	47.2	14,140
0	79	16.5	3,480	30.8	14,080	17	590	5.2	2,340	6,240	55.2	19,360
0	81	18.7	3,735	33.7	15,810	15	660	5.3	3,000	7,155	63.4	24,120

Table 16. – *Yields per acre for upland oak; first thinning at age 50 (Gingrich 1971)*

Age	Residual stand: Basal area	Residual stand: Average tree diameter	Residual stand: Yield			Cut stand: Basal area	Cut stand: Yield			Cumulative total yields (cut stand plus residual stand)		
ars	*Square feet*	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
	SITE INDEX 55											
0	69	6.5	1,627	14.9	400	28	523	4.8	--	2,150	19.7	400
0	66	8.4	1,710	14.7	1,350	23	317	3.9	150	2,550	23.4	1,500
0	68	9.3	1,855	15.4	3,585	15	280	3.2	165	2,975	27.3	3,900
0	71	10.5	1,960	18.0	6,160	12	280	2.1	325	3,360	32.0	6,800
0	73	11.5	2,115	20.0	8,240	10	220	2.2	620	3,735	36.2	9,500
10	74	12.7	2,250	22.8	8,900	9	230	1.5	1,240	4,100	40.5	11,400
	SITE INDEX 65											
0	75	8.0	2,130	19.6	1,850	30	670	7.3	300	2,800	26.9	2,150
0	68	9.6	2,130	19.5	4,090	29	470	4.4	210	3,270	31.2	4,600
0	70	10.4	2,240	20.6	6,160	18	400	3.7	330	3,780	36.0	7,000
0	74	12.2	2,480	22.8	8,240	14	300	2.6	520	4,320	40.8	9,600
0	77	14.8	2,745	25.2	10,305	12	275	2.7	935	4,860	45.9	12,600
10	79	17.0	3,000	28.5	10,700	10	235	1.8	1,905	5,350	51.0	14,900
	SITE INDEX 75											
0	78	9.0	2,590	24.4	3,650	32	725	5.7	450	3,315	30.1	4,100
0	72	11.3	2,700	25.2	6,300	30	655	6.8	1,050	4,080	37.7	7,800
0	75	12.8	2,965	26.8	9,200	19	475	5.2	1,100	4,820	44.5	11,800
0	77	14.1	3,180	29.0	11,500	18	425	4.8	1,500	5,460	51.5	15,600
0	79	16.5	3,620	31.4	13,000	16	420	4.6	1,900	6,320	58.5	19,000
10	81	18.4	3,880	33.0	14,450	14	500	4.9	2,750	7,080	65.0	23,200

Table 17. – *Yields per acre for upland oak; first thinning at age 60 (Gingrich 1971)*

Age	Residual stand: Basal area	Residual stand: Average tree diameter	Residual stand: Yield			Cut stand: Basal area	Cut stand: Yield			Cumulative total yield (cut stand plus residual stand)		
Years	*Square feet*	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
SITE INDEX 55												
60	76	8.2	1,860	17.1	780	28	660	5.8	120	2,520	22.9	90
70	73	9.3	1,960	17.5	2,345	19	285	4.0	685	2,905	27.3	3,15
80	70	10.3	2,000	18.4	4,320	16	335	3.0	555	3,280	31.2	5,68
90	72	11.3	2,115	19.3	5,850	10	250	2.5	530	3,645	34.6	7,74
100	74	12.3	2,200	20.8	7,300	8	270	1.9	510	4,000	38.0	9,70
110	75	13.2	2,310	22.6	8,580	7	235	2.0	570	4,345	41.8	11,55
SITE INDEX 65												
60	78	9.4	2,400	22.2	3,900	33	900	8.6	1,260	3,300	30.8	5,16
70	75	10.2	2,450	22.1	4,550	23	360	3.6	770	3,710	34.3	6,58
80	73	12.0	2,520	23.0	5,920	20	400	3.6	810	4,180	38.8	8,76
90	77	14.1	2,610	23.8	7,785	13	365	3.6	895	4,635	43.2	11,52
100	78	15.5	2,650	25.5	9,850	12	325	3.1	915	5,000	48.0	14,50
110	80	17.2	2,750	26.6	11,770	9	345	3.1	960	5,445	52.2	17,38
SITE INDEX 75												
60	82	10.2	3,060	27.0	7,848	32	1,080	10.7	1,440	4,140	37.7	9,28
70	78	11.5	3,150	27.3	8,540	21	460	4.7	870	4,690	42.7	10,85
80	76	13.5	3,320	28.4	9,760	21	420	4.2	1,290	5,280	48.0	13,36
90	78	15.6	3,510	29.9	10,935	16	425	3.6	1,665	5,895	53.1	16,20
100	80	17.2	3,725	31.5	12,200	13	415	3.3	1,835	6,525	58.0	19,30
110	82	19.1	3,795	33.0	13,530	9	445	3.2	1,920	7,040	62.7	22,55

Table 18. – *Yields of well-stocked unmanaged mixed oak stands in southern Michigan at 80 years*[1] *(Arend and Scholz 1969)*

D.b.h. class (inches)	Total trees of all species	Basal area	Per acre volume[2]		
	Number per acre	*Sq. ft. per acre*	*Cu. ft.*	*Cords*	*Bd. ft.*
VERY POOR SITES					
5-10	194	59.7	838	10.5	900
11-13	36	27.9	432	5.4	
Total	200	87.6	1,270	15.9	
POOR SITES					
5-10	174	53.9	765	9.6	2,535
11-15	59	47.3	1,003	12.5	
Total	233	101.2	1,768	22.1	
MEDIUM SITES					
5-10	89	29.4	475	5.9	
11-22	81	86.5	1,944	24.3	5,650
Total	170	115.9	2,419	30.2	
GOOD SITES					
5-10	81	21.7	414	5.2	
11-25	88	107.7	3,080	38.5	11,440
Total	169	129.4	3,494	43.7	
VERY GOOD SITES					
5-10	55	17.4	378	4.7	
11-24	95	125.4	5,130	64.1	19,950
Total	150	142.8	5,508	68.8	

[1]Adapted from Michigan Agricultural Experiment Station Tech. Bull. 236 (Gysel and Arend 1953).

[2]Cubic foot volume based on main stem, less bark; cord volume based on all merchantable wood to a 4-inch top, outside bark; board foot volume by International 1/4-inch log rule.

Table 19. – *Gross yields per acre of normal oak stands in southwestern Wisconsin (Gevorkiantz and Scholz 1948)*

Age (Years)	Total volume: Cubic feet[1]	Cords[2]	Board feet Scribner[3]
VERY POOR SITE			
20	480	--	--
40	1,050	10	--
60	1,550	19	550
80	2,000	25	2,500
100	2,350	29	4,550
120	2,650	33	6,300
140	2,900	36	7,600
160	3,050	38	8,500
POOR SITE			
20	650	1	--
40	1,350	15	--
60	1,950	25	2,300
80	2,550	32	6,400
100	3,050	38	9,600
120	3,450	42	11,700
140	3,750	46	13,150
160	3,900	49	14,000
MEDIUM SITE			
20	850	2	--
40	1,750	21	300
60	2,550	33	4,700
80	3,300	41	10,200
100	3,900	49	13,600
120	4,350	54	15,800
140	4,750	58	17,300
160	4,950	61	18,500
GOOD SITE			
20	1,000	3	--
40	2,050	25	1,600
60	3,050	39	7,600
80	3,950	50	13,400
100	4,700	59	17,200
120	5,300	66	19,600
140	5,700	71	21,000
160	5,950	74	22,100
VERY GOOD SITE			
20	1,150	4	--
40	2,400	30	2,800
60	3,600	46	10,500
80	4,600	59	16,800
100	5,500	69	21,100
120	6,200	77	23,900
140	6,700	83	25,500
160	7,000	87	26,700

[1]Gross volume, excluding bark, all trees 0.6 inch d.b.h. and larger.

[2]Gross volume, excluding bark to top diameter of 4 inches, all trees 5 inches d.b.h. and larger.

[3]Scaled in 8 foot logs. If scaled in 16-foot logs, reduce table values by 11 percent.

APPENDIX III

EVALUATING STAND DENSITY AND GROWING STOCK QUALITY

The basic data needed to evaluate stand stocking and quality are *basal area* and *number of trees per acre* (by size class and growing stock quality class). Stocking percent and average stand diameter are determined from figure 7 using these two data items. The charts in figure 7 show how well a particular stand is utilizing its growing space, and how much of the stand can be removed in an intermediate cut. The inventory to obtain these data is left to the discretion of the user, but should be intense enough to provide reliable estimates of stand parameters.[2] Four size classes are defined as follows:

Mature Timber – trees that have reached the rotation diameter desired for the site.

Sawtimber – trees over 11 inches d.b.h. but less than the rotation diameter desired for the site.

Poletimber – trees 6 to 11 inches d.b.h.

Small Trees – trees 2 to 6 inches d.b.h.

The class limits were selected to conform to commonly accepted usage, but may be changed to meet the needs of the user.

Two growing stock quality classes are suggested within three of the above size classes. (They are not needed in the mature timber class because these trees are ready for harvest.) These quality classes are good or "acceptable growing stock" (AGS) and "undesirable growing stock" (UGS). AGS trees are trees of good form, quality, and species that would be satisfactory crop trees in the final stand on the site, or have the potential of yielding products in a future intermediate cutting within 20 to 40 years. UGS trees are trees that are salable for products or that might eventually be salable if left to grow, but because of form, defect, vigor, or species, are not wanted in the stand.

Cull trees are trees that are not and never will be merchantable for products and should be tallied without regard for size class.

[2] *The method suggested by Roach and Gingrich (1968) is recommended. Tree size classes and quality classes are the same as they suggest.*

When the stand inventory has been completed, stocking chart can be used to determine present stock and the amount of basal area that can be removed i cut. Assume the following information has been tained from the inventory:

Site class 55 to 74
Rotation diameter objective 20 to 24 inches
Number of trees per acre - 220
Basal area per acre

	AGS	UGS	Cull	To
Mature timber	–	–	–	–
Sawtimber	32	2	3	37
Poletimber	18	2	1	21
Small trees	10	20	0	30
Total	60	24	4	88

Referring to the stocking chart (fig. 7), locate point where total basal area and number of tr intersect to find the current stocking percent (80) a average stand diameter (8.6 inches). Then project a l parallel to the line denoting 8 inches average diameter the B and C curves to find the basal area needed B-level (64), and C-level (50) stocking. Now, comp the basal area of acceptable growing stock from the ta with that required for B and C levels determined fr the chart.

In the example, there are 60 square feet of basal a in acceptable growing stock, not quite enough for B le but well above C level. Inspection of the data shows t stand is immature but no single size class contains m than 50 percent of the basal area. The sawtimber a pole classes must be combined to form the main stand stand to manage. Twenty-four square feet of basal a can be removed from this stand in an intermediate c without falling below B-level stocking (88-24=64). No that not all culls and undesirable growing sto (24+4=28) can be removed and retain B-level stocki (64-24=40). The cut should be designed to remove t cull trees and as much undesirable growing stock possible and still retain uniform spacing.

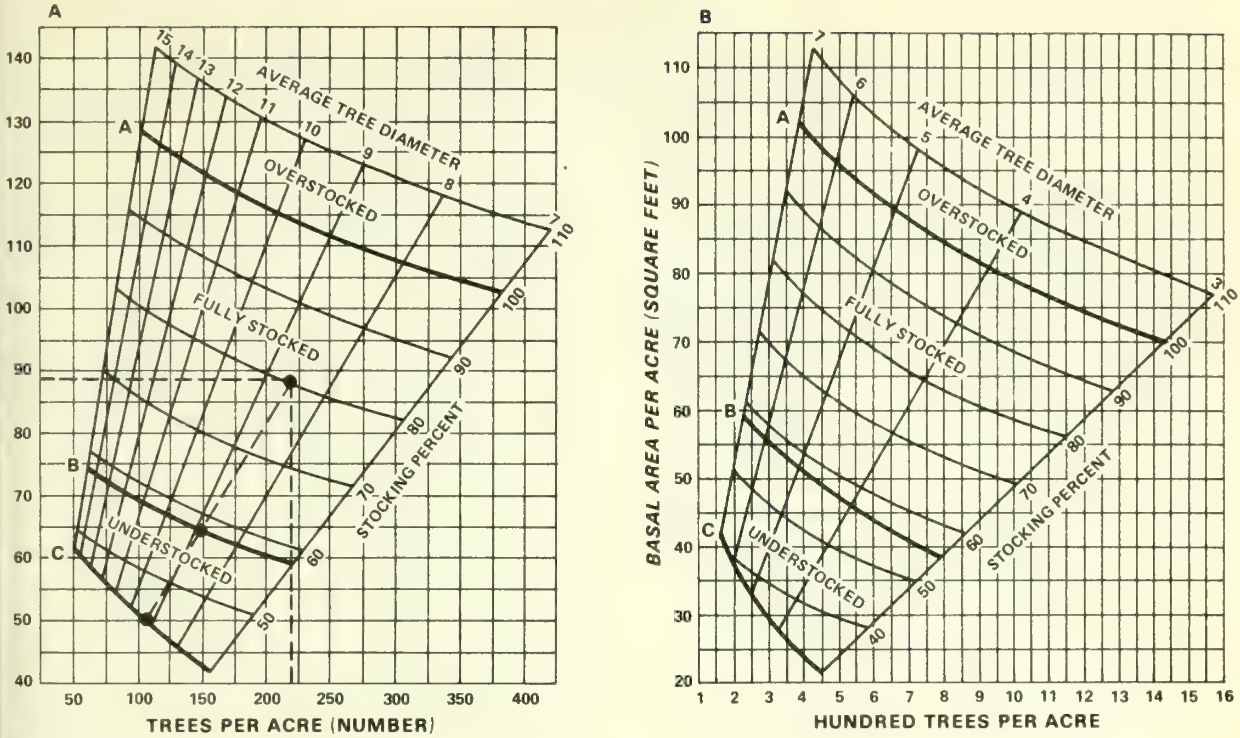

Figure 7. – *Relation of basal area, number of trees, and average tree diameter to stocking percent for upland central hardwoods. For average tree diameters 7 to 15, use the chart at left; for diameters 3 to 7, use the chart at right. (Average tree diameter is the tree of average basal area.) On both charts the area between curves A and B indicates the range of stocking where trees can fully utilize the site. Curve C shows the lower limit of stocking necessary to reach the B level in 10 years on average sites (Gingrich 1971).*

APPENDIX IV

EVALUATING THE ADEQUACY OF OAK ADVANCE REPRODUCTION

To evaluate whether the oak advance reproduction can adequately reproduce the stand a survey must be made. This survey can be made at the same time that the inventory to determine stand stocking and quality is made. In fact, the *number of overstory trees per acre* from the stand stocking inventory is needed to estimate the *number of stump sprouts per acre* necessary to compensate for oak advance reproduction deficiencies. The sample form (fig. 8) can be used to record the tree count needed for estimating number of overstory trees per acre.

Use the following procedure developed by Sander *et al.* (1976) for evaluating oak advance reproduction:

1. Take 10 or more 10-factor angle gauge sample points in the stand being examined. At each sample point tally the trees on a 1/20-acre plot by species and size class (overstory inventory, see sample form, figure 8).

2. Select the number of 1/735-acre plots (4.3 feet in radius) to use in the advance reproduction inventory from the following tabulation according to the acreage of the stand being examined:

For stand size (acres)	Use this number of 1/735-acre plots
<10	25
10 to 30	40
30 to 50	60

3. Distribute these 1/735-acre plots uniformly throughout the stand.

4. On each 1/735-acre plot look for oak reproduction stems 4.5 feet tall or taller and less than 2.0 inches in diameter at the ground line or not over 1.5 inches d.b.h. (stems larger than this should be considered part of the overstory and tallied as such, even if below the main canopy). If at least one such stem is present, record the plot as stocked. If no such stem is present, record the plot as not stocked (see right margin of sample form, figure 8).

5. Compute the percent of plots stocked. If 59 percent or more are stocked, there is adequate oak advance reproduction present; no further calculations are necessary and the stand may be harvested.

6. If fewer than 59 percent of the plots are stocked, oak advance reproduction is inadequate to reproduce the stand if it is cut. But the stand could still be reproduced if enough stumps of the overstory oaks will sprout after they are cut. An example of how to compute the expected number of stump sprouts follows:

a. Assume that the inventory of plots provides the data on the sample worksheet (fig. 8).

b. Note that there are 26 black oaks 2 to 5 inches in diameter per acre. Multiply 26 by 0.85 (from table 20) to find how many of the 26 stumps would be expected to sprout. 26 x 0.85 = 22. Note that 22, number of expected stump sprouts per acre for 2- to 5-inch black oaks, is listed at the bottom of figure 8.

c. Similarly, compute the expected number of stump sprouts for the other size classes of black oak (5 for the 6- to 11-inch class, 4 for the 12- to 16-inch class) and note that all these classes sum to 31. Do the same for all oak species.

d. Summing size classes for all oaks gives a total of 124 expected oak stump sprouts per acre (fig. 8).

7. Note that the sample data from figure 2 gave 17 plots stocked of a total of 40, or 43 percent of plots stocked (determined under point 4 above). Go to the tabulation below and find the number of stump sprouts required in combination with

Table 20. – *Expected percentage of oak stumps that wi[ll] sprout after cutting*[1]

Size class[2] (inches)	Black oak	Scarlet oak	Northern red oak	White oak	Chestnut oak
2-5	85	100	100	80	100
6-11	65	85	60	50	90
12-16	20	50	45	15	75
17+	5	20	30	0	50

[1] Adapted from Roth and Hepting (1943), Wendel (1975), Johnson (1975), and unpublished data at Columbia, Missouri.

[2] D.b.h. class of parent tree.

stocked plots to meet minimum stocking requirements at the next lowest percent down from 43 (i.e., 40). Opposite 40 note that 95 stump sprouts are needed to make up the deficiency in advance reproduction.

Stocked 1/735-acre plots (Percent[3])	Stump sprouts required (Number per acre)
59	0
55	19
50	44
45	69
40	95
35	120
30	145
25	170
20	196
15	221
10	246

8. Because the computed value (124) exceeds the tabulation value (95), there will be enough oak stump sprouts to make up the advance reproduction deficiency. Thus, the oak component of the new stand will be adequate and the old stand can be harvested.

9. If the number of expected stump sprouts does not compensate for advance reproduction deficiencies, harvesting should be delayed until adequate oak advance reproduction is established and reaches the minimum size of 4.5 feet in height.

10. Unless the stand is protected or the wildlife controlled, it will probably be impossible to get adequate natural oak reproduction in areas where deer browsing is heavy and where there are high populations of acorn-consuming wildlife. The alternative is to plant oak seedlings and protect them from wildlife.

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[3] If the percent of stocked plots lies between the 5-percent intervals, use the lower figure, e.g., 43 percent stocked plots should be considered 40 percent.

Sample point number	Dbh class	Black oak	White oak	Scarlet oak	Northern red oak	Chestnut oak	Other species	Total
1	2-5							
	6-11							
	12-16							
	17+							
2	2-5							
	6-11							
	12-16							
	17+							
3	2-5							
	6-11							
	12-16							
	17+							
4	2-5							
	6-11							
	12-16							
	17+							
5	2-5							
	6-11							
	12-16							
	17+							
6	2-5							
	6-11							
	12-16							
	17+							
7	2-5							
	6-11							
	12-16							
	17+							
8	2-5							
	6-11							
	12-16							
	17+							
9	2-5							
	6-11							
	12-16							
	17+							
10	2-5							
	6-11							
	12-16							
	17+							
Total No. per acre	2-5	26	60	24	4		26	140
	6-11	8	12	2	4		22	48
	12-16	18	8	4	2		14	46
	17+	2	2	0	2		0	6
	Total	54	82	30	12		62	240
No. of stump sprouts per acre	2-5	22	48	24	4			Total per acre
	6-11	5	6	2	2			
	12-16	4	4	2	1			
	17+	0	0	0	0			
	Total	31	58	28	7			124

Date

Compartment 1

Stand 1

1/735-acre plots

Total No. 40

Stocked

Not Stocked

Percent Stocked 43

Adv. Repro. Adequate No

Adv. Repro. + stump sprouts Adequate Yes

Figure 8. - *Example tally form for recording on 1/20-acre plots and number of 1/735-acre plots stocked with advance oak reproduction.*

APPENDIX V

MISCELLANEOUS

Metric Conversion Factors

convert	*to*	*Multiply by*
res	Hectares	0.405
ard feet[1]	Cubic meters	0.005
ard feet/acre[1]	Cubic meters/hectare	0.012
ains	Meters	20.117
rds[1]	Cubic meters	2.605
rds/acre[1]	Cubic meters/hectare	6.437
bic feet	Cubic meters	0.028
bic feet/acre	Cubic meters/hectare	0.070
grees Fahrenheit	Degrees Celsius	[2]
et	Meters	0.305
llons	Liters	3.785
llons/acre	Liters/hectare	9.353
ches	Centimeters	2.540
les	Kilometers	1.609
les/hour	Meters/second	0.447
mber/acre	Number/hectare	2.471
nces	Grams	28.350
nces/acre	Grams/hectare	70.053
unds	Kilograms	0.454
unds/acre	Kilograms/hectare	1.121
unds/gallon	Kilograms/liter	0.120
uare feet	Square meters	0.093
uare feet/acre	Square meters/hectare	0.230
ns	Metric tons	0.907
ns/acre	Metric tons/hectare	2.242

[1]The conversion of board feet and cords to cubic ters can only be approximate; the factors are based an assumed 5.663 board feet (log scale) per cubic ot and a cord with 92 cubic feet of solid material.

[2]To convert °F to °C, use the formula 5/9 (°F-32) $\frac{°F-32}{1.8}$.

Common and Scientific Names of Plants and Animals

Plants

Anthracnose	*Gnomonia quercina*
Ash, white	*Fraxinus americana*
Aspen	*Populus* spp.
Basswood, American	*Tilia americana*
Blackgum	*Nyssa sylvatica*
Blister, leaf	*Taphina* spp.
Butternut	*Juglans cinerea*
Blueberry	*Vaccinium* spp.
Cankers	*Strumella* spp.
	Nectria spp.
Cherry, black	*Prunus serotina*
Dogwood, flowering	*Cornus florida*
Elm, American	*Ulmus americana*
Hazelnut	*Corylus americana*
Heartrots	*Poria* spp.
	Stereum spp.
	Hericuim spp.
	Irpex spp.
	Polyporus spp.
Hophornbeam, eastern	*Ostrya virginiana*
Hornbeam, American	*Carpinus caroliniana*
Maple, red	*Acer rubrum*
Maple, sugar	*Acer saccharum*
Oak, black	*Quercus velutina*
Oak, blackjack	*Quercus marilandica*
Oak, bur	*Quercus macrocarpa*
Oak, chestnut	*Quercus prinus*
Oak, northern red	*Quercus rubra*
Oak, post	*Quercus stellata*
Oak, scarlet	*Quercus coccinea*
Oak, white	*Quercus alba*
Sassafras	*Sassafras albidum*
Walnut, black	*Juglans nigra*
Wilt, oak	*Ceratocystis fagacearum*
Witchhazel	*Hammamelis virginiana*
Yellow-poplar	*Liriodendron tulipifera*

Animals

Bobcat	*Lynx rufus*
Borer, red oak	*Enaphalodes rufulus*
Borer, white oak	*Goes tigrinus*
Carpenterworm	*Prinoxystus robiniae*
Caterpillar, forest tent	*Malacosoma disstria*
Caterpillar, variable oak leaf	*Heterocampa manteo*
Chipmunk, eastern	*Tamias striatus*
Deer, white-tailed	*Dama virginiana*
Fox, red	*Vulpes vulpes*
Grouse, ruffed	*Bonasa umbellus*
Moth, gypsy	*Porthetria dispar*
Oakworm, orangestriped	*Anisota senatoria*
Oppossum	*Didelphis marsupialis*
Raccoon	*Procyon lotor*
Roller, oak leaf	*Archips semiferanus*
Root rot	*Armillaria mellea*
Skunk	*Mephitis* spp.
Squirrel, fox	*Sciurus niger*
Squirrel, gray	*Sciurus carolinensis*
Tier, oak leaf	*Eroesia albicamana*
Turkey, wild	*Meleagris gallopavo*
Weevils, acorn	*Curculis* spp.

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key – out of the reach of children and animals – and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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Sander, Ivan L. 1977. Manager's handbook for oaks in the north central States. USDA For. Serv. Gen. Tech. Rep. NC-37, 35 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

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KEY WORDS: *Quercus*, mixed stands, regeneration, thinning.

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Nature is beautiful...leave only your footprints.

manager's handbook for BLACK WALNUT

ENERAL TECHNICAL REPORT NC- 38

ORTH CENTRAL FOREST EXPERIMENT STATION FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

Other Manager's Handbooks are:

- Jack pine – GTR-NC-32
- Red pine – GTR-NC-33
- Black spruce – GTR-NC-34
- Northern white-cedar – GTR-NC-35
- Aspen – GTR-NC-36
- Oaks – GTR-NC-37
- Northern hardwoods – GTR-NC-39

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FOREWORD

This is one of a series of manager's handbooks for important forest types or species in the north-central States. The purpose of this series is to present the resource manager with the latest and best information available on handling these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. However, ways to modify management practices to maintain or enhance other values are included where sound information is available.

The authors have, in certain instances, drawn freely on unpublished information provided by scientists and managers outside their specialties. They are also grateful to the several technical reviewers in the region who made many helpful comments.

The handbooks have a similar format, highlighted by a "Key to Recommendations". Here the manager can find in logical sequence the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbook. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objectives. The manager should also apply new research findings as they become available so that the culture of these important forest types can be continually improved.

CONTENTS

BLACK WALNUT

Richard C. Schlesinger, *Principal Silviculturist*

and

David T. Funk, *Principal Plant Geneticist*
Carbondale, Illinois

KEY TO RECOMMENDATIONS

The following key is intended to facilitate quick access recommendations covering any site or stand likely to encountered in walnut management. It is important that the management objectives be clearly in mind before entering the key (Management Objectives, below).

Poor or questionable walnut site	CONSIDER OTHER SPECIES (see p. 3)
Good walnut site (site index 40 or more)	2
2. No walnut trees	PLANT OR SEED (see p. 6)
2. Walnut trees present	3
Trees less than 10 feet (3m) tall	CONTROL WEEDS AND IMPROVE FORM IF NEEDED (see p. 9)
Trees taller than 10 feet (3m)	4
4. Scattered walnut trees in natural stands, pastures, or fence rows	MANAGE INDIVIDUAL TREES (see p. 14)
4. Walnut plantations or pure natural stands	5
Product goals attained	HARVEST AND REGENERATE (see p. 15)
Product goals not attained	THIN, PRUNE, AND/OR FERTILIZE AS NEEDED (see p. 12)

GENERAL CONSIDERATIONS

The decision to grow and manage black walnut should e based upon the following questions. First, are the oils and climate in the management area suitable for alnut; that is, is it biologically possible to grow walnut? econd, are the resources available to invest in management; that is, is it economically feasible? And, finally, hat are the interests of, and the other management ptions available to, the landowner; that is, is it desirable manage walnut? This handbook will address primarily ie biological question.

Management Objectives

In the following tabulation, likely management opons are indicated by an "X"; those marked with a uestion mark would be feasible only in special situaons.

	Timber	Timber & Nuts	Multi-cropping
"Bare" land	X	X	X
Newly established plantation	X	X	?
Previously unmanaged plantation	X	X	?
Young natural stand			
—many walnut	X	X	?
—few walnut	X	–	–
Older natural stand			
—many walnut	X	X	–
—few walnut	X	–	–

Habitat Conditions

The frost-free season within the range of black walnut (fig. 1) varies from 140 days in the north to 280 days in

Figure 1. – *Natural range for black walnut,* Juglans nigra.

western Florida. Annual precipitation in this region varies from less than 25 inches (64 cm) in northern Nebraska to 70 inches (178 cm) or more in the Appalachians of Tennessee and North Carolina. Temperatures as low as -45°F (-43°C) have occurred where walnut grows.

Associated Trees and Shrubs

Black walnut grows in many of the mixed mesophytic forests but is seldom abundant. It generally is found scattered among other trees; pure stands are of limited extent, usually found on the edge of the forest. Chief associates include yellow-poplar (see Appendix, p. 19, for list of scientific names), white ash, black cherry, basswood, beech, sugar maple, oaks, and hickories. The eastern redcedar-hardwood type of Kentucky and central Tennessee often contains a relatively high percentage of black walnut. Near the western limits of the tree's range, it may be confined to floodplains and occur either with American elm, hackberry, green ash, and boxelder, or with basswood and red oak on lower slopes and other favorable sites.

No universal plant indicator of a good black walnut site is known, but the presence of Kentucky coffeetree seems to indicate a suitable site for walnut. In general, where yellow-poplar or white ash grow well, black walnut also thrives.

An antagonism between black walnut and many other plants growing within its root zone has been recognized and is attributed to a toxic substance, juglone, which is present in black walnut leaves and especially in roots and nut hulls. Plants known to be affected include tomatoes, alfalfa, and many coniferous species.

Reproduction and Early Growth

Flowering and Seed Production

Depending somewhat on latitude, black walnut flow generally appear between mid-April and mid-June. T large, edible fruit ripens in September or October of same year, usually dropping shortly after the leaves f

Seed crops are produced most commonly in alternate-year cycle, but some trees bear annually, oth in 1 or 2 years out of each 3, and many with regular pattern at all. Although open-grown trees p duce some seed as early as 4 years after planting, minimum seed-bearing age for commercial quantities seed is about 12 years. Best seed production begins wh the trees are about 30 years old and continues another 100 years.

The large, distinctively flavored nuts furnish food squirrels and make up as much as 10 percent of the c of eastern fox squirrels. Many nuts buried by squirr are not recovered, and some sprout and establ additional trees, particularly on the fringes of exist stands.

Seedling Development

Many black walnut seedlings germinate from n buried by squirrels in the fall. Normal freezing a thawing usually will cause the seeds to break dorma the following spring, but germination may be delay sometimes until the second year.

Most seedlings emerge between late April and ea June of the first or second spring after seeding. Altho black walnut does not make as rapid height growth yellow-poplar and white ash on good sites, it gener surpasses the oaks. In eastern Nebraska, near the west limits of its range, walnut made much better hei growth than oaks and basswood on a prairie site developed an excellent root system and was several ti the height of the other trees.

Height growth begins rather slowly in the spr reaches a peak rate in May or early June, and essentially complete by the middle of July or the firs August. Diameter growth peaks in July and contin into mid-August; root growth ends in mid-September general, black walnut loses its leaves somewhat ear than other trees and over its range has a growth pe of 90 to 135 days.

'egetative Reproduction

If small black walnut trees up to age 20 or 30 are cut r killed back by fire, the stumps usually sprout freely; prouting is more erratic from stumps or trees from age 0 to 40. Stumps usually sprout at or about ground vel.

Sapling Stage to Maturity

Trees 130 feet (40 m) tall and over 8 feet (2.5 m) in iameter at age 250 have been reported in Wisconsin. In idiana, black walnut trees were 150 feet (46 m) in eight and 6 feet (1.8 m) in diameter on the most vorable sites.

teaction to Competition

Black walnut is an intolerant tree. In mixed forest ands, it must be in a dominant or codominant position maintain itself, although it has survived and grown in e relatively light shade of black locust. Near the estern limits of its range, black walnut may be part of e elm-ash-hackberry type that succeeds pioneer trees cluding willow, eastern cottonwood, and boxelder on ottomlands.

Open-grown trees tend to retain their lower branches definitely. Heavy artificial pruning is impractical be-use of sprouting from dormant buds. Sprouting is rectly related to the amount of light reaching the bole; ore branches may be removed from trees in dense ands than from open-grown trees. Dominant trees rout less than intermediates. Trees that are drastically leased from competition may develop epicormic anches.

Site Evaluation

Black walnut is sensitive to soil conditions, developing st on deep, well-drained, nearly neutral soils which are nerally moist and fertile. This species is common on nestone soils and grows especially well on deep loams, ess soils, and fertile, well-drained alluvial deposits.

Failure to consider site quality is a common and rious mistake in walnut management. A thorough soil amination by a soils specialist is the best procedure. A ss accurate, but generally useful, method is to deter-ine site quality from index curves (fig. 2), if there are alnut trees 15 years of age or older on the area. Do not anage for walnut if the site index is less than 40.

If there are no walnuts of sufficient age for site index determination, analyze the topography and soil to assess site quality. In strongly rolling and mountainous areas, landscape position and slope aspect, as well as soil characteristics, are important in site selection. The better growing areas are typically located on the lower north- and east-facing slopes, stream terraces, and floodplains. Avoid steep, south- and west-facing slopes and narrow ridgetops.

In smooth and gently rolling areas, soil characteristics are more important than landscape position. The three most important soil factors for walnut are texture, depth, and drainage. Either use a soil auger or dig a soil pit to check soil characteristics to a depth of 3 feet (1 meter) (see Appendix, p. 19, for metric conversions). The topsoil should be a sandy loam, loam, or silt loam, while the subsoil should be one of the above or a sandy clay loam or clay loam. Soils derived from limestone with silt loam over clayey subsoils are good planting sites. Soils with acid clayey subsoils should be avoided, as should soils with coarse sand or gravel layers or bedrock within 2.5 feet (0.8 meters) of the surface.

A uniform brown, yellowish-, or reddish-brown color to 3 feet or more indicates satisfactory drainage. Avoid soils with evidence of mottling within 2.5 feet of the surface. A soil with red, yellow, or gray spots (mottles) or a uniform gray color generally indicates slow to very slow internal drainage.

Nutrient Requirements and Fertilization

If walnut trees are growing on the proposed site, their foliage can be checked for any serious deficiency symptoms (table 1). Chemical analysis of foliage can diagnose less extreme nutrient deficiencies that have no visible symptoms and also suggest if the trees will respond to fertilization (table 2). Not much is yet known about fertilization. Field fertilization research has been conducted only with the macro-nutrients (N, P, K, Ca), with variable response. It is not possible to make specific recommendations for specific soils at the present time, but, in general, nitrogen fertilization appears to be most promising. Fertilization of pole-size trees is likely to provide the best economic returns. It may be necessary to refertilize every 5 years or so in order to maintain growth stimulation. Fertilization should be considered a supplement to other cultural practices, and cannot be expected to compensate for other limiting soil factors such as poor moisture conditions.

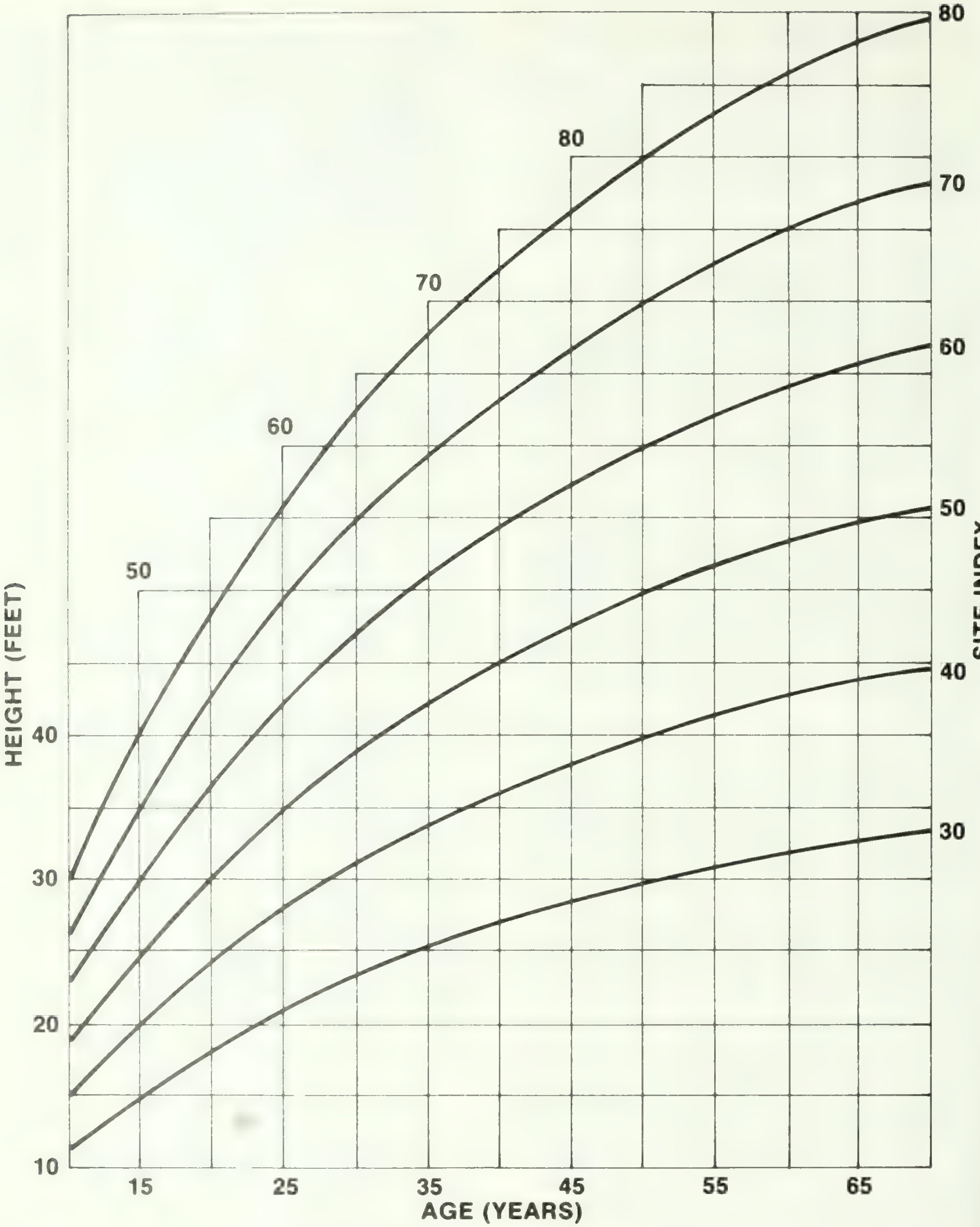


Figure 2. *Black walnut site index curves.*

Protection from Damaging Agents

Although older black walnut trees are quite windfirm and not easily damaged by ice or windstorms, young trees are susceptible to top breakage during early summer storms while the new growth is still succulent.

Numerous insects and diseases attack black waln but the "big three" for the grower are the wal caterpillar, the bud borers and casebearers, and anthr nose. The black walnut caterpillar is a defolia Damage varies from year to year, but repeated defo tion can lead to the death of the tree. Bud borers a

Table 1. – *Deficiency symptoms for various nutrients in leaves of black walnut seedlings*[1]

Nutrient	Most apparent deficiency symptoms
N	Leaflets and rachis small. Leaflets yellow to yellow-green, veins yellow. Leaflets have a crinkly appearance. Number of leaflets reduced.
P	Leaflets and rachis small. Yellowish rachis. Chlorotic areas on the leaflets between veins. Lateral leaflets exhibit bronzing. Number of leaflets reduced.
K	Leaflets light yellowish green with marginal yellowing, especially at tips. Rachis yellow-green to yellow. Leaves small. Number of leaflets reduced.
Ca	Leaves very small. Leaflets have chlorotic areas and patches of light green to yellow. Terminal leaflet has tip burn. In extreme case, leaf loses practically all green coloring and appears bleached and whitish. Number of leaflets reduced.
Mg	Leaf size about normal. Some small chlorotic areas. Leaflets yellow-green to light green. Veins remain green. Number of leaflets normal.
S	Leaves small. Leaflet color pale green to almost bleached white. Veins near base of leaflet darker green than other leaflet tissue. Rachis green to purplish. Number of leaflets normal.
Fe	Similar to sulfur except less reduction in leaflet size and veins remain green especially adjacent to the mid-vein. Leaflet surface smooth. Number of leaflets normal.
Mn	Leaf size about normal. Rachis is brownish, basal leaflets show bleaching along margins, and overall leaf color is yellow-green. Number of leaflets normal.

[1]Hacskaylo, Finn, and Vimmerstedt, 1969.

Table 2. – *Tentative critical foliar nutrient levels*[1] *for diagnosing nutrient deficiencies in black walnut trees*

Nutrient	Deficient (will probably respond to fertilization)	Intermediate (may or may not respond to fertilization)	Adequate (will probably not respond to fertilization)
	Percent		
N	below 2.00	2.00 - 2.60	over 2.60
P	" .10	.10 - .25	" .25
K	" .75	.75 - 1.30	" 1.30
Ca	" .50	.50 - 1.10	" 1.10
Mg	" .15	.15 - .45	" .45
S	" .05	.05 - .25	" .25
	Parts per million		
Fe	" 40	40 - 100	" 100
Mn	" 30	30 - 80	" 80
B	" 20	20 - 50	" 50
Zn	" 15	15 - 50	" 50
Cu	" 5	5 - 10	" 10
Mo	" .05	.05 - .10	" .10

[1]Based on analyses of mature leaves collected about mid-August (Phares and Finn 1971).

casebearers are particularly important during the early years of plantation establishment, boring into the buds and causing forking of the main stem. Anthracnose is a leaf spot disease that may cause premature leaf drop and loss of growth, and may induce the degrade of nut quality known as 'ambers'.

Adults of the walnut caterpillar are present during the spring and summer. They are stout-bodied moths, have wingspreads of about 2 inches, and are dull brown to chestnut brown in color. Egg-laying begins in June, the eggs being deposited in masses on the underside of leaves. The larvae feed in colonies. Full-grown larvae are up to 2 inches long, black with longitudinal, yellowish stripes, and covered with long white or dirty gray hairs. Insect parasites and birds control them naturally to a limited extent. The least expensive direct control measure is to destroy the colonies of larvae by removing them from the tree and burning or squashing them.

Several species of bud borers and casebearers have been found on black walnut. Although at some stage in their life cycle they feed on the leaves, the major damage is to the buds and developing shoots, and can be mistaken for frost injury. In either case, killing of the terminal bud or shoot often results in the development of more than one lateral bud. Control measures have n yet been developed. Ways to improve the form affected trees are discussed on page 9.

Anthracnose leaf spot appears as irregular circular da spots scattered over the leaflets early in the summer. T spread of anthracnose is more rapid during wet weath Infection can be heavy enough to blight most of the le and cause it to drop prematurely. How much it affe tree growth has not been determined. It is believed th nut crop failures in some cases may be directly attrib able to anthracnose, and control may be necessary f the production of nuts. Control is possible through t application of fungicides, such as Cyprex which presently registered, or Benlate (registered only for u on nonbearing trees).[1]

Fire is another threat to black walnut. Although t evidence of damage following a ground fire is n immediately apparent, the living tissue directly bene the bark can be killed by the high temperatures. T bark itself may remain in place over the dead wood several years, but the wound to the valuable first log h already occurred. Where the danger of fire exists, f buildup in young plantations can be controlled mowing grasses and weeds in the fall.

PLANTING

Intensive culture of black walnut is most feasible (and most necessary) in pure stands, but these are rarely encountered in nature. A major portion of this handbook is thus devoted to planting and to plantations where intensive culture can be practiced. Before actual planting, spacing, site preparation, plant material, and planting method must all be considered.

Spacing

To a considerable extent, appropriate spacing in walnut plantations is dictated by management objectives. We will consider plantations intended to produce timber alone, timber and nuts, and those with multiple-use objectives.

Objective: Timber

For plantations intended solely for timber production plant trees approximately 10 x 10 feet (3 x 3 meters) apart. Plantations established at such an initial spacing can be reduced from 436 to 23 trees per acre (1,077 57 trees/hectare) through a sequence of five thinni (see example, Appendix, p. 17). The final thinning to trees/acre at an average spacing of 44 x 44 feet (1 meters) will allow the trees to reach an average d.b.h. 23.4 inches (59 cm) at harvest. This average diame can be achieved only through selecting the fas growing trees to retain at each thinning. If the origi planting comprises only 23 trees to be grown to fi harvest, average d.b.h. for the same period of time estimated to be only 19.6 inches (50 cm). Retain only trees with above average growth rates results i stand averaging 3.8 inches (9 cm) larger in d.b.h. harvest and containing 50 percent more merchanta volume.

Relatively close initial spacing (10 x 10) can also expected to result in improved tree form, through b the training effect of adjacent trees and the grea

[1] *See Pesticide Precautionary Statement, p. 20.*

mber from which to select better formed individuals. final reason for close spacing is that trees removed in er thinnings should yield merchantable products (see aintaining Quality and Growth, p. 12). The dis-vantages of close spacing are obvious: increased costs r planting stock and weed control, and extra labor quired for planting, tending, and removing the addi-nal trees. On balance, we recommend spacing planta-ns for timber at about 10 x 10 feet (3 x 3 meters); mewhat irregular spacings such as 8 x 12 feet (2.5 x 5 meters) may be preferable in some situations to ow use of machinery through the wider dimension.

bjective: Timber and Nuts

Stocking in plantations intended to produce both nber and nuts should be maintained at lower levels an for timber production alone. An initial spacing of x 15 feet (4.5 x 4.5 meters) is recommended. At this acing, the first thinning will not be needed until erage stand d.b.h. is 5.6 inches (14 cm). Regular nut oduction should have begun on trees of this size and es to be retained after the first thinning can be aluated on the basis of nut yield and quality as well as r timber traits.

bjective: Intercropping

In walnut plantations intended for multiple use to oduce forage, hay, sod, or row crops, spacing will obably have to be unusually wide in at least one rection. Wide spacing will allow efficient use of fencing prevent livestock from damaging young trees and will ow turning room for large farm equipment. However, acing within rows should be close to allow the ection of desirable individuals as in pure plantations. acings such as 5 x 30 or 5 x 40 feet (1.5 x 9 or 1.5 x meters) should be considered, but the actual arrange-ent of the planting will of course be dictated by the ecific crops to be grown and the equipment to be ed.

Site Preparation

Walnuts can be planted successfully on a variety of es, but intensive follow-up culture is usually necessary the plantations are to become satisfactorily estab-hed. Thorough site preparation, in addition to its lditional benefits, greatly expedites subsequent cul-ral practices.

utover Sites

Selection or shelterwood systems for regenerating rest stands are not effective for establishing walnut plantations on forested sites. Although some walnut seedlings will survive for a few years under partial cover, they grow satisfactorily only following complete overstory removal. All woody vegetation larger than 1/2 inch (1.3 cm) d.b.h. should be cut; stumps 8 inches (20 cm) or less in diameter should be treated immediately with a low-volatile ester formulation of 2,4,5-T[1] to inhibit sprout competition. Site preparation on clearcut sites need not include removal of all slash, since it is unlikely that power equipment such as tractor-hitched mowers or sprayers can be operated among the stumps. It is important for planted rows to be sufficiently clear so that planted trees can be readily located, weeds controlled around them, and corrective pruning accomplished as necessary.

Brushy Fields

Walnuts may be interplanted in brushy fields if the site is good. Such sites justify removal of brush for planting at regular spacing, use of power equipment, and intensive culture; on marginal brushy sites other species requiring little or no tending after planting should be considered instead of walnut. Cut stumps should be treated with herbicide to minimize sprouting.

Weeds and Grasses

It is neither necessary nor desirable to destroy all standing herbaceous vegetation in an old field prior to planting walnuts. Erosion is likely to be accelerated on completely cleared sites, even though they may appear to be almost level. Strips mowed at the same spacing as the intended planting may expedite the subsequent planting job. This practice works well in fields covered with a heavy stand of dead annual weeds; the intervening strips of weeds that remain will provide desirable protection from winds.

It is feasible and sometimes convenient to apply herbicides in strips or spots to kill grass sod prior to planting. If the herbicides are applied in the early spring before planting, the dead grass will mark the planting spots. Combinations of simazine and dalapon and simazine and paraquat have proved effective for this sort of advance weed control, but at the time of writing, simazine is not registered for use on walnut plantations during the first year (see Establishment and Ensuring Good Form, page 9).

Although plowing and discing prior to planting are not necessary for successful plantation establishment, trees planted in plots plowed and disced before applying

herbicide will eventually outgrow those planted in sod. One obvious effect of plowing grassy fields before planting is the conversion of the ground vegetation to predominantly broadleaf weeds. Simazine works effectively on germinating weed seeds, so weed control with simazine is more complete on areas prepared by plowing than on established sod. On the other hand, plowing may encourage the development of deep-rooted perennial weeds such as trumpetcreeper.

Plant Material

Seed Source

Black walnut occurs naturally over a broad range, extending into 33 States and Ontario. Studies have shown that walnut trees originating south of the planting site grow for a longer period during the growing season than those of local or northern origin. In several test plantings, trees originating well to the south consistently outgrew those of local provenance. At present we recommend using seed from sources up to 200 miles (320 km) south of the intended planting site; seed from more than 50 miles (80 km) north of the planting area should not be used unless it is collected from tested and proved trees or stands.

From the standpoint of just timber production, growing walnut for veneer offers by far the greatest profit potential. Intermediate products such as firewood, fence posts, small dimension parts, and even sawtimber are much less valuable. To insure that sufficient numbers of trees will reach veneer size, we need genetic diversity in walnut plantations. Over the several decades required to produce veneer timber, the plantations will be subject to attack by an assortment of disease and insect pests, including some that are probably not important at this time. Various "unusual" climatic conditions will occur and reoccur. It is unreasonable to expect seedling progeny of any single parent tree, even a "superior" one that is pollinated by another selected parent, to be satisfactorily resistant to all possible adverse situations. The only protection lies in establishing a sufficiently broad genetic base in each plantation. Do not plant seed or seedlings derived from one or only a few trees, no matter how beautiful the parent trees look or how well the seedlings grow in the nursery. Planting an assortment of seedlings (ideally derived from seed orchards containing many tested-and-proved parents) provides cheap and effective insurance against disaster that might strike just as the trees are increasing most in value.

Seedling Quality

Large black walnut seedlings outgrow small ones o
variety of sites, and seedlings 1/4-inch (6 mm) or lar
in caliper are recommended for planting. Seedli
showing signs of root rot or that have stems black a
apparently dead (as might be caused by freezing in
nursery) should be discarded.

Care of Seed and Seedlings

Nuts to be direct-seeded in the spring can be stratif
in outdoor pits or in plastic bags in cold-storage roo
Pit-stored seed usually germinates somewhat better a
can be held for as long as 4 years without serious l
of viability. Unless properly dried, seed held in plas
bags in cold storage will begin to germinate in the b
about 7 to 10 months after collection and must
promptly sowed before it is lost.

Walnut seedlings properly packed at the nursery can
held in cold storage overwinter, at least as long a
months. Seedlings received in the spring should not
allowed to freeze or overheat. Seedlings can be sto
under shade – such as in an unheated warehouse – up
2 weeks before planting. If they have been prope
packed, no more than one drenching of the seedl
roots should be necessary to keep them in go
condition. If planting must be delayed more tha
couple of weeks, seedlings should be heeled in or kep
refrigerated storage.

Planting Method

Direct Seeding

Pilferage by squirrels and other rodents severely lin
successful direct seeding of walnuts. Loss can
minimized by using mechanical barriers made of ha
ware cloth or punctured cans, but these devices
expensive to prepare and put in place. Several chem
treatments have been devised in attempts to re
rodents or to conceal planted nuts, but none h
proved effective.

Several factors, including luck, may combine to al
successful direct seeding. First, in seasons with he
natural mast crops, rodents will be less ambitious ab
digging up planted seed. Further, squirrels are reluct
to travel more than 330 feet (100 meters) acı
open country so planting sites located at such a dista
from standing timber can be safely seeded. Fina
rodents will pilfer walnuts at any season, but sowing
in the spring, and using seed that have already begu

erminate, will reduce the period of vulnerability. When lanting germinating seeds, care must be taken to rotect the emerging radicle from breaking.

Planting of Seedlings

Walnut seedlings may be successfully planted by any ustomary machine or hand method. The only necessary equirements are that the seedlings be planted upright and the entire root system buried without distortion. Reasonable root pruning, top pruning, or both (roots should not be pruned to less than 8 inches (20 cm) long) are acceptable but not essential. Deep planting is not advantageous and may be detrimental. Because of the need to control potential competing vegetation around the seedlings, spring planting is recommended; in areas where all weeds have been killed, fall planted trees are susceptible to frost-heaving over the ensuing winter.

ESTABLISHMENT AND ENSURING GOOD FORM

Intensive culture is essential in walnut plantations until ney are successfully established and the trees are at least to 10 feet (3 meters) in height. The emphasis during nis period should be on growing a stem that is straight, ee of defects, and can be converted into a veneer log of t least minimum dimensions. This objective can be met y using cultural techniques that correct defects through irect action and also by maintaining optimum environ-nental conditions that stimulate trees to overgrow efects before they become serious. Most recommended ractices are appropriate for use in young naturally egenerating walnut stands as well as in plantations.

Weed Control

Control of competing grasses and forbs is especially nportant in plantations being established in fields reviously used for agriculture. Complete weed control neither necessary nor desirable since it aggravates rosion problems.

On sites suitable for intensive walnut culture, control f competing weeds for the first 3 years after planting hould ensure that the trees will grow well during the rucial period when form is determined. One or 2 ears of weed control are usually sufficient to ensure atisfactory establishment, but the third year stimulates eight growth equivalent to at least an extra year's ncrement. Weed control for more than 3 years, espe-ially on a larger area around each tree, will continue to timulate growth, but costs may not justify it.

Planted walnut trees grow faster when weeds are ontrolled by herbicides than by either mulching or ultivation. Simazine is the preferred chemical for ontrolling germinating seeds and has been used effec-ively with dalapon (for standing grasses), 2,4-D (for broadleaved weeds), or both. At the time of writing, only simazine among these chemicals is registered for use with black walnut, and then only in plantations that have been established for a year or more; expanded pesticide labels have been proposed that will allow use of other herbicides in walnut plantings.[1] Simazine should be applied at the rate of 4 pounds active ingredient per acre of area treated (4.5 kg/ha) on sandy loam soils and 5 pounds per acre (5.6 kg/ha) on clay loam soils. Paraquat is a registered and effective herbicide that kills standing weeds but must be used with care because of high toxicity to mammals.

Depending on terrain and available equipment, herbi-cides may be applied in strips along rows of trees, or to circular areas surrounding the trees. Spot diameter and strip width need not be wider than 4 feet (1.2 meters) for the first 2 years. During the third year, some additional tree growth may be gained by increasing spot diameter to 5 or 6 feet (about 2 meters).

In plantings established on cleared forest sites, compe-tition from herbaceous weeds is likely to be much more critical than that from woody vegetation. Weed control methods used in other planting situations should be adequate for use in forest openings.

Maintaining Stem Form

During the first season after planting, walnut seedlings may die back from the tip and subsequently sprout from lateral buds. Dieback related to planting shock is relatively widespread, especially on less-than-ideal sites or when the summer after transplanting is unusually dry. Damage to leader tips in subsequent years can also be caused by deer browsing, late spring frosts, and es-pecially by insect attack (see Protection from Damaging Agents, p. 4).

When lateral branches sprout following dieback of terminals, some young trees produce a relatively straight new leader, others develop a strong fork, and many exhibit some intermediate type of form – a moderate crook or a weak fork. Because of the premium value of straight veneer logs, it is tempting to take immediate action to shape up potentially crooked trees, but it isn't always necessary.

Some trees are obvious candidates for corrective pruning, those with evenly balanced "slingshot" forks, for instance. Most of these forks can be straightened at an early age using masking tape, pruning shears, and Bey's "new twist" technique (fig. 3). The procedure goes as follows:

1. Select the strongest, most promising shoot – one with a healthy terminal bud.
2. Bend it so that the tip is as close as possible to being over the central axis of the main stem.
3. Select another shoot (or two, if necessary) that will hold the terminal in position.
4. Secure the terminal in position by wrapping 1-inch wide masking tape around both the terminal and the supporting lateral. Branches larger than 3/4 inch in diameter and branches with angles wider than 45° exert more pressure and may require additional wraps of tape. Most will be secured near the top of the terminal.
5. Cut off the tip of the supporting lateral branch to eliminate potentially competing new growth. This may mean cutting off only the terminal bud or perhaps many inches of the lateral branch.

The procedure can be used shortly before or soon after growth begins in the spring. New leaves interfere with taping, and therefore it can be done more rapidly before growth begins.

At the beginning of the third or fourth growing season after planting, trees with potentially poor form are usually obvious and still small enough to correctively prune. Not all poorly formed trees need to be corrected; they can safely be neglected if they are surrounded by trees with good form in sufficient number to make a stand after thinning.

Trees without a potential strong leader should be coppiced if they seem likely to be needed beyond the first thinning; after they sprout from the root collar, the sprout clumps should be thinned to the single best stem. Coppicing should be done in the spring before the beginning of the third or fourth growing season for two reasons: first, regrowth of the new sprout never quite catches up to that of the original stem, but cutting at

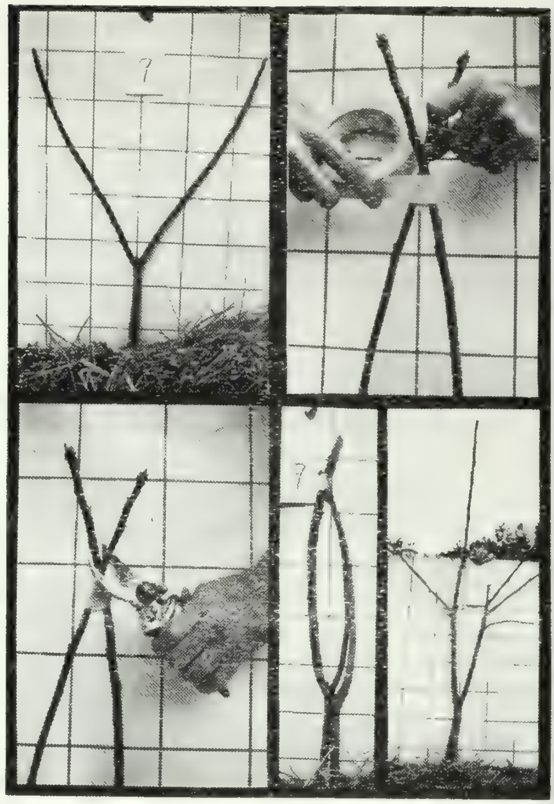
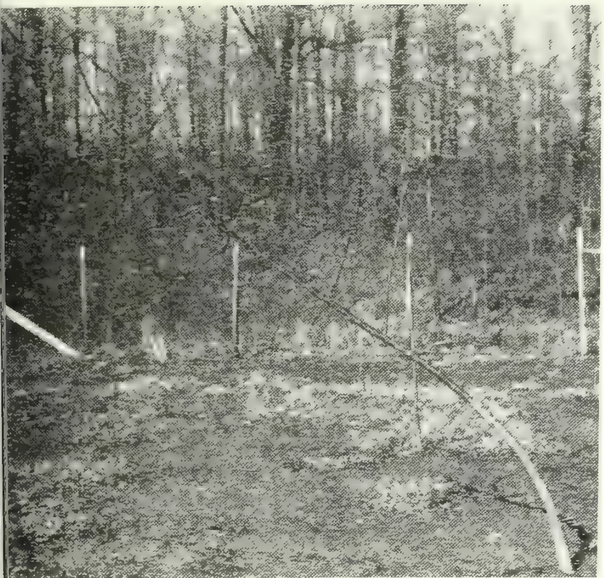


Figure 3. – *Masking tape and hand clippers are usef tools for developing straight boles on young blac walnut trees.*

this relatively early age minimizes the increment lo second, if trees older than 5 years are coppiced, t sprouts will grow so fast that they may not sta upright.

Corrective pruning should not be confused with later pruning (page 12) which is intended to promote develo ment of knot-free wood. Lateral pruning is not approp ate when the tree is being cultured for good form exce to remove some lower branches to prevent their bei run over and torn out by vehicles being operat between plantation rows. Zealous attempts to minimi the size of the knotty core by early clear-length pruni sometimes have disastrous consequences (fig. 4).

Another good procedure that is recommended f "correcting" poor stem form is the exercise of patien Despite the accidents that befall them, most bla walnut trees in plantations have a strong natural ten ency to grow upright. Crooks that appear to potentially disastrous in a shoulder-high tree often tu



gure 4. — *Branches were pruned from about 70 percent of the total height of this young walnut. It produced numerous bole sprouts and heavy foliage and toppled over during a summer windstorm.*

t to be innocuous after the tree has grown to be 3 4 meters tall. Crooked young trees make differ- tial radial growth, adding more wood on the concave e of the crook than on the convex. Furthermore, they o straighten physically; the combination of the two ocesses can result in dramatic improvement in form g. 5).

Fertilization

As a general rule, fertilizing walnut plantations during the establishment years is a mistake. On the high quality sites suited to intensive culture, soil nutrients are usually not limiting to walnut growth, but fertilizer treatments may stimulate weed competition. On mediocre sites, tree growth may sometimes be increased through fertilization, but rotations are still likely to be lengthy because of other limiting soil factors such as inadequate moisture or poor aeration. On such sites, fertilization during the increment phase (see page 14) is probably a better bet, because the investment will not have to be carried for such a long time.

Intercropping

Walnut plantations interplanted with agronomic crops may require special cultural practices. For instance, livestock must not be allowed to browse young trees; a portable electric fence system may be arranged that permits rotational pasture grazing without damage to the walnuts (fig. 6).

If herbicides are used to control weeds competing with planted walnuts, each case must be considered separately since some chemicals are not registered for use with planned agricultural crops. In other cases, the herbicides may be registered and usage compatible, but scheduling of sowing, harvesting, or grazing may need to be modified to comply with label restrictions.

Spring 1975

Fall 1976

Figure 5. — *In two growing seasons, the stem of this tree has moved 9 inches closer to the vertical position.*

Figure 6. – *Closeup of a young black walnut interplanted with soybeans in Missouri. The spacing is 40 feet x 40 feet. (Photo courtesy of Gene Garrett, University of Missouri.)*

Maintaining good stem form may be more difficult in intercropped plantations in which the walnut trees are irregularly spaced. The trees are likely to be more exposed to environmental stress and also to damage by agricultural equipment. An extra year of corrective pruning is likely to be necessary. Some lateral pruning to avoid damage by equipment may also be appropriate.

Other trees or shrubs may also be interplanted with walnut for any of a number of reasons: for esthetic values, to provide wildlife cover or food, for an intermediate crop such as Christmas trees, to serve as trainers for the walnut trees, or, in the case of nitrogen-fixing species, to stimulate growth of the walnuts. Interplanting can thus be used as at least a partial substitute for corrective pruning and fertilization. Of the many species that have been used for interplanting, we suggest autumn-olive as worthy of further trial. Autumn-olive is an attractive shrub that bears bright red berries relished by songbirds and game birds. It fixes atmospheric nitrogen and adds it to the soil in a form available to other plants.

Autumn-olive grows at a rate more like that of walnut than either black locust or European alder. These species also fix nitrogen but are likely to overtop walnut trees in only 4 or 5 years on most good sites. In five Midwestern plantations, autumn-olive grew at an average rate of about 2 feet (0.6 meters) per year for the first 7 years after planting and is expected to level off at about 15 feet (4.5 meters). Walnuts interplanted with the autumn-olive reached 15.1 feet (4.6 meters) at the same age, while solid walnut plantings were only 9.7 feet (3.0 meters) tall. Stem form and natural pruning of walnuts interplanted with autumn-olive were also superior to those in pure stands. Specific recommendations for spacing and thinning schedules remain to be worked out, but interplanting with autumn-olive is tentatively recommended.

MAINTAINING QUALITY AND GROWTH

Once walnut trees are taller than 10 feet (3 meters), techniques to maintain the growth of selected crop trees and improve the quality of the merchantable portion of the stem become paramount. Quality improvement can be achieved through lateral pruning, while maintaining growth involves thinning and fertilization.

Pruning

Pruning of lateral branches helps to produce knot-free wood under growing conditions (wide spacing) that would normally permit most of the lower branches to persist. Crowding sufficient to stimulate natural pruning would also decrease diameter growth. The objective of pruning is to produce a clear bole while minimizing damage to the tree and loss of growth. Normally pruning should be done in several stages.

Branches should be pruned before they are 2 inches (5 cm) in diameter to minimize damage and promote rapid healing. A neat, clean cut should be made, preferably using a pruning saw. Pruning wounds made during the dormant season (early spring is best) tend to heal more rapidly and completely and sprouts from dormant buds near the wound are less likely to develop. If sprouts do develop, they should be promptly removed.

Start pruning as soon as the trees are taller than 10 feet (3 meters). Prune from 25 to 100 potential crop trees per acre (60 to 250 per hectare) and only trees less than 10 inches (25 cm) in diameter. No more than 25 percent of the live crown should be removed in a single year, and the live crown length ratio should be maintained at no less than 50 percent. Pruning should proceed in stages until at least the first 9 feet (2.7 meters) of the bole are clear. For veneer and timber production, the first 17 feet (5.2 meters) should be pruned. Costs increase rapidly for upper log pruning, while the returns from the smaller upper logs are less than for the first log.

Thinning

Periodic thinning provides the opportunity for selecting the better trees to retain as their superiority becomes apparent. If the plantation were not thinned, the faster-growing trees would eventually out-compete their neighbors, but at a considerable sacrifice in their own growth. The objectives of thinning are: (1) to maintain rapid growth of all potential crop trees while delaying the selection of the actual crop trees for as long as possible, and (2) if possible, to grow the trees to be removed to a size sufficient to yield salable intermediate products.

Crown competition factor (CCF) is a useful tool for deciding when to thin and how much to leave. Based on the size of an open-grown tree's crown, this measure of crowding provides an objective method for assessing plantation stocking. At CCF = 100, the sum of the tree crown areas equals the area of the plantation or stand. Given any two of four stand parameters (basal area per acre, number of trees per acre, average diameter, and CCF), the other two can be obtained from graphs (fig. 7); or the last three parameters can be obtained more precisely by using a table (see Appendix for table 3 and an example). CCF should not be used if spacing is highly irregular; e.g., if the distance between rows is more than twice the distance between trees within rows. Although optimum CCF levels for walnut management are not known, the following paragraphs discuss tentative recommendations and considerations.

Management objectives will dictate the appropriate upper limits for stocking levels. Nut production will require stocking levels of 90 CCF or less; the upper levels for timber and veneer production may be as high as 110 CCF. For optimum growth of individual trees, lower levels of stocking may be required on dry sites than on moist sites.

The first step in using CCF to guide thinning decisions is to select upper and lower CCF levels between which plantation stocking will be maintained. When the upper level is reached, the plantation should be thinned back to the lower level. The difference between the upper and lower levels will determine how often thinnings will be

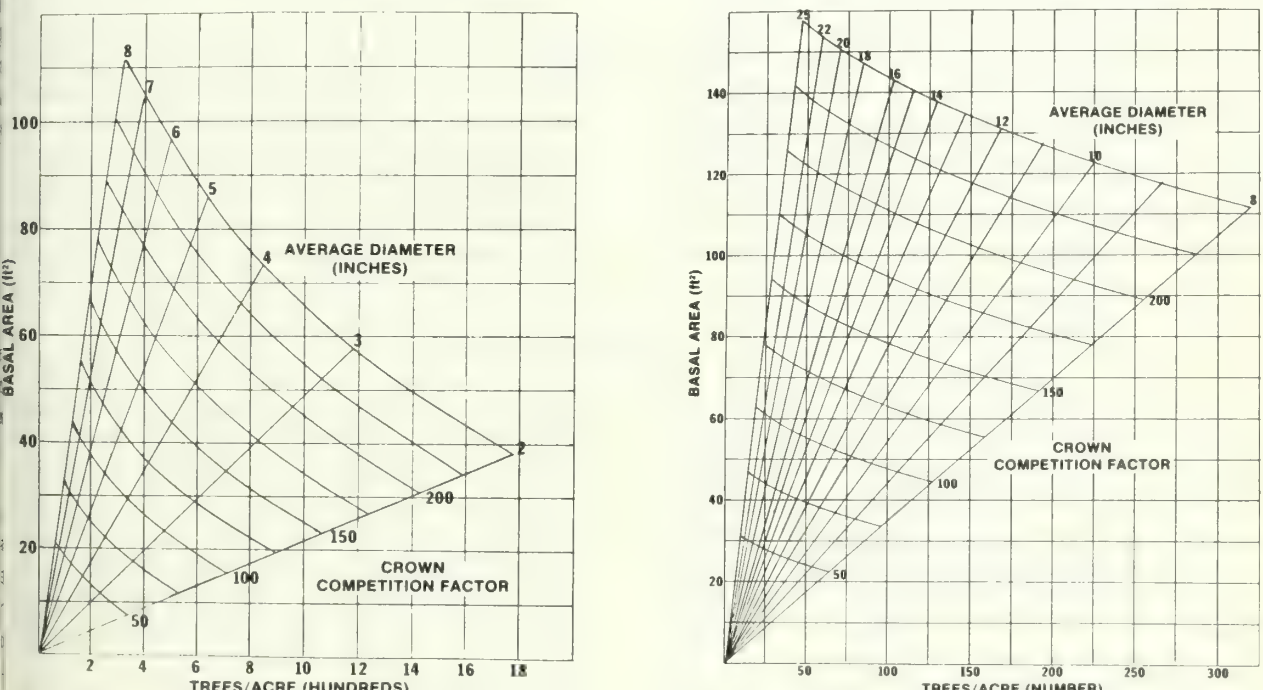


Figure 7. —*Stocking for trees (left) 2 to 8 inches in diameter, and (right) 8 to 25 inches in diameter.*

required. If the difference is small, frequent light thinnings will be needed. Thinning to reduce CCF by 40 will generally result in removing 40 to 60 percent of the trees (see example in Appendix).

Although the determination of when to thin and how many trees to leave can be arrived at objectively using CCF, the selection of the trees to leave must be a subjective, on-the-ground determination. Strictly mechanical spacing would defeat the purpose of having a population of trees to select from, but consideration of spacing in conjunction with crop tree selection is necessary. In general each crop tree should benefit from thinning by the removal of at least one competing neighbor. Generally if 50 percent of the trees are cut, most of the crop trees will have two or three nearest neighbors removed.

Until the trees to be removed are of sawtimber size, the markets for thinning products are rare. In certain situations markets for small furniture-type dimension material or other products may exist to help offset the cost of thinning, but in general thinnings must be considered a necessary investment for the production of high-quality timber products in the least amount of time. Once the trees reach sawtimber size, thinning should be profitable.

Plantations for which CCF is not appropriate because of irregular spacing should be thinned when the theoretical crown width is twice the distance between the trees in the rows. Theoretical crown width is calculated using the following formula: crown width (feet) = 1.993 times d.b.h. (inches) plus 4.783. After one or more thinnings, spacing will become more regular, and CCF can be used.

For mixed-species stands including walnut and for plantations in which stocking levels have reached CCF 160 or more, thinnings using the stocking-guide approach are not appropriate. Crop tree release following the guidelines for single tree culture (below) offers a better solution for the mixed stand and for the initial treatment in the overstocked stands. Reducing the stocking to the appropriate lower CCF level in one operation could result in epicormic branching. Following this first treatment, the plantations can be brought under the stocking guide procedure.

Fertilization

Foliage analysis currently provides the best diagnostic tool for deciding whether fertilization is needed or beneficial (see Nutrient Requirements and Fertilization, page 3). Fertilization cannot be considered in isolation from other cultural practices. If the trees are crowded, thinning or release should precede fertilization, and if a well-established understory is present, it may be necessary to control the understory in order to allow the added nutrients to reach the trees.

Intercropping

The walnut trees will increasingly occupy a higher proportion of the plantation area as they develop, decreasing the intercropping options. Most row crops require full sunlight for growth, so that once stocking levels of 50 CCF or more are reached, this option is no longer viable.

Pasturing can continue to be an intercropping option until the trees reach maturity. Once the walnut trees are stout enough (4 to 6 inches or 10 to 15 cm in diameter) and tall enough (a clear bole length of 9 feet or 3 meters) light, well-regulated grazing will cause little or no damage. Heavy grazing with its associated soil compaction and physical damage to the root systems can reduce sawtimber yields by as much as 20 percent.

SINGLE TREE CULTURE

Release

More than for any other American timber species, intensive culture of individual black walnut trees is economically justified. Furthermore, most walnuts respond well to culture whether they occur as scattered trees in a mixed forest or singly in a pasture or open grove.

Release is the first item to be considered for individual trees in a forest. Dominant and codominant trees can be expected to continue to grow more rapidly than those in intermediate or suppressed classes, but strong intermediates often respond most to release (in terms of relative increase in growth rate). Any walnut tree that is healthy, has a bole with potential to make a veneer or high-quality log, and is small enough that it can reasonably be left to grow for at least ten more years should be considered a candidate for release.

To be effective, release must be thorough. One rule of thumb is that at least three-fourths of the crown of the

eleased tree should be at least 5 feet (1.5 meters) from he crowns of adjacent trees 60 to 100 percent as tall nd at least 10 feet (3 meters) from the crowns of taller ees. After the walnuts have responded to release, the icreased growth should be maintained at a uniform ite. The crowns of trees that have been released as well s surrounding trees can be expected to expand rapidly. Vhen walnut crop trees are no longer free to grow, ubsequent releases should be made, probably at interals of about 6 to 10 years.

Some bole sprouting can be expected on forest-grown ees that are released for the first time. Most of the prouts will occur above the butt log so little extra runing will be required.

Pruning

By definition, open-grown trees need no release, but ney, as well as many forest-grown trees, can almost ways benefit from pruning of side branches. Ideally, runing should start before branches are more than 2 iches (5 cm) in diameter at the butt; minimizing wound ize minimizes the time until wound closure. Because of he characteristic rapid diameter growth of walnut trees the open, somewhat larger pruning wounds can be olerated than in trees in plantations or natural stands. s branches grow larger than 3 inches (8 cm) in closed stands, or 4 inches (10 cm) on open-grown trees, pruning should be suspended except for removal of dead branches.

Fertilization

Although results from a number of field fertilization trials are not completely consistent, they may be summarized as follows. Diameter growth is often increased as much or more by release than by fertilization. Nitrogen fertilization stimulates diameter growth more than does phosphorus or potassium treatment. All three elements – N, P, and K – may be effective in stimulating increased nut production, sometimes doubling or tripling the crop produced by released but unfertilized trees. Fertilization is not effective in stands 60 years of age or older.

At present we recommend fertilizing pole-sized trees managed for timber production with 10 pounds (4.5 kg) of urea spread around the tree over an area about 10 meters in diameter; for combined production of timber and nuts, 5 pounds (2.3 kg) of triple superphosphate, and 8 pounds (1.8 kg) of muriate of potash should be added. All fertilized trees should be free to grow or else released in advance; treatments can be repeated at 5-year intervals. To verify that fertilized trees are responding to treatment, several similar trees should be left as unfertilized "check trees".

HARVESTING

When to make the final harvest depends upon the roject objective, market conditions, and the potential icrease in value if harvesting is deferred. Also to be onsidered at harvest time is the question of whether or ot to establish a new stand of walnut, and if so, how.

Product Specification

Most black walnut is grown to produce veneer and aw logs. There are no standardized specifications for eneer trees. Veneer buyers have their own systems for electing and evaluating potential trees for their partiular needs. The seller can obtain a fair market price for is timber through competitive bidding between two or nore potential buyers, but there is presently no objecive procedure for assessing the market value of walnut eneer trees.

Saw log trees can be evaluated more objectively using andard tree grades and current selling prices. The high value of walnut compared to other timber species results in greater dollar variation around the average selling prices. Thus, although a reasonable estimate of log value can be made, the actual market value may vary considerably from this estimate.

Growth and Yield

Intensive management of black walnut plantations is recent enough that no growth and yield information is available for managed plantations, and the limited information available from unmanaged plantations is considered too conservative for managed plantations. To indicate future growth and yield when it is most needed – during the final stage of growth just before harvest – use the past performance of the plantation. Standard form-class volume tables can be used in combination with projected diameter growth to estimate volume increment for the next 5- to 10-year period, with sufficient accuracy for planning purposes.

Regeneration

Once the decision to harvest has been made, the establishment of a future stand must be considered if the land is to remain in forest. If the walnut to be harvested is scattered as individuals in a mixed hardwood forest, the recommended regeneration methods for the specific forest type should be followed.

If the walnut to be harvested is in a pure stand or plantation, the surest way to regenerate it is by planting (see page 6). Not enough is known yet about regenerating a pure stand or plantation to assure success. If it is tried, the seeds need to be buried or pressed into the ground (to get moisture for germination) and seedlings must be released from shade after a few years. Indeed the number of seedlings surviving decreases by about two-thirds each year. Discing or rolling the plantation area following a good seed year, then the prompt removal of the overstory once sufficient seedlings are present, is suggested.

APPENDIX

Stocking Guide Example

To use a measure of stocking to guide thinning decisions, you must select upper and lower CCF levels between which stocking will be maintained. When the upper level is reached, the plantation should be thinned back to the lower level. The difference between the upper and lower levels determines how often thinnings will be required. The larger the difference between the levels, the fewer thinnings will be required.

Besides determining the upper and lower levels, the following also must be known before decisions can be made as to when and how much to thin: (1) number of trees per acre, and (2) the average tree d.b.h. If any two of these three variables are known, the third can be determined by using the charts on page 13, or the conversion tables shown in table 3 in the Appendix and this formula: CCF = average crown area x number of trees per acre.

For example, thinning decisions for a plantation initially composed of 436 trees per acre could be derived as follows:

Select an upper CCF level of 110, appropriate for veneer production, and a lower CCF level of 70. The 110 level would be divided by 436, which would give the average crown area of 0.252. This corresponds to the average tree size of 3.5 inches shown in table 3 in the Appendix. Therefore, the first thinning on this plantation would be made when the average size of the trees had reached 3.5 inches.

To determine how much to thin, however, it is necessary to estimate the average tree size after thinning. Based on the limited data available at this time, the diameter after thinning can be calculated by multiplying 3.5 inches by 1.04 and then adding 0.4 inch. Therefore, the estimated average diameter of the crop trees would be 4.0 inches.

To determine the number of trees to leave, the lower CCF level, 70, would be divided by 0.298, which is the average crown area shown for a 4.0-inch tree in table 3 in the Appendix. This would show that 235 trees should be left.

Using the same procedure, a schedule for subsequent thinnings on this plantation could be set up as follows:

BEFORE THINNING

	Trees/acre (Number)	Average d.b.h. (Inches)
First thinning	436	3.5
Second thinning	235	5.6
Third thinning	131	8.4
Fourth thinning	73	12.1
Fifth thinning	41	16.9
Harvest	23	23.4

AFTER THINNING

	Trees/acre (Number)	Average d.b.h. (Inches)
First thinning	235	4.0
Second thinning	131	6.2
Third thinning	73	9.1
Fourth thinning	41	13.0
Fifth thinning	23	18.0
Harvest		

This procedure can be used with all upper and lower stocking levels and with any number of trees per acre.

Table 3. – *Tree crown area*
(In percent of an acre)

Diameter at breast height										
Inches	Tenths of inches									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.085	0.090	0.095	0.100	0.106	0.111	0.117	0.123	0.129	0.135
2	.142	.148	.155	.161	.168	.175	.182	.190	.197	.205
3	.212	.220	.228	.236	.245	.253	.262	.270	.279	.288
4	.298	.307	.316	.326	.336	.345	.356	.366	.376	.386
5	.397	.408	.419	.430	.441	.452	.464	.475	.487	.499
6	.511	.523	.535	.548	.560	.573	.586	.599	.612	.625
7	.639	.653	.666	.680	.694	.708	.723	.737	.752	.766
8	.781	.796	.812	.827	.842	.858	.874	.889	.906	.922
9	.938	.955	.971	.988	1.005	1.022	1.039	1.056	1.074	1.091
10	1.109	1.127	1.145	1.163	1.182	1.200	1.219	1.238	1.256	1.275
11	1.295	1.314	1.333	1.353	1.373	1.393	1.413	1.433	1.453	1.474
12	1.494	1.515	1.536	1.557	1.578	1.600	1.621	1.643	1.665	1.686
13	1.708	1.731	1.753	1.775	1.798	1.821	1.844	1.867	1.890	1.913
14	1.937	1.960	1.984	2.008	2.032	2.056	2.081	2.105	2.130	2.155
15	2.180	2.205	2.230	2.255	2.281	2.306	2.332	2.358	2.384	2.410
16	2.437	2.463	2.490	2.516	2.543	2.570	2.598	2.625	2.653	2.680
17	2.708	2.736	2.764	2.792	2.821	2.849	2.878	2.906	2.935	2.964
18	2.994	3.023	3.052	3.082	3.112	3.142	3.172	3.202	3.232	3.263
19	3.294	3.324	3.355	3.386	3.418	3.449	3.481	3.512	3.544	3.576
20	3.608	3.640	3.673	3.706	3.738	3.770	3.803	3.837	3.870	3.903
21	3.937	3.970	4.004	4.038	4.072	4.106	4.141	4.175	4.210	4.245
22	4.280	4.315	4.350	4.385	4.421	4.456	4.492	4.528	4.564	4.600
23	4.637	4.673	4.710	4.747	4.784	4.821	4.858	4.896	4.933	4.971
24	5.009	5.046	5.085	5.123	5.161	5.200	5.238	5.277	5.316	5.355
25	5.394	5.434	5.473	5.513	5.553	5.593	5.633	5.673	5.714	5.754
26	5.795	5.836	5.876	5.918	5.959	6.000	6.042	6.083	6.125	6.167
27	6.209	6.252	6.294	6.336	6.379	6.422	6.465	6.508	6.551	6.595
28	6.638	6.682	6.726	6.770	6.814	6.858	6.902	6.947	6.992	7.036

CCF = (table value) (number of trees per acre)

$$\text{Table value} = \frac{\text{CCF}}{\text{number of trees per acre}}$$

$$\text{Number of trees per acre} = \frac{\text{CCF}}{\text{table value}}$$

Metric Conversion Factors

o convert	to	Multiply by
cres	Hectares	0.405
oard feet[1]	Cubic meters	0.005
oard feet/acre[1]	Cubic meters/hectare	0.012
nains	Meters	20.117
ords[1]	Cubic meters	2.605
ords/acre[1]	Cubic meters/hectare	6.437
ubic feet	Cubic meters	0.028
ubic feet/acre	Cubic meters/hectare	0.070
egrees Fahrenheit	Degrees Celsius	[2]
eet	Meters	0.305
allons	Liters	3.785
allons/acre	Liters/hectare	9.353
nches	Centimeters	2.540
iles	Kilometers	1.609
iles/hour	Meters/second	0.447
umber/acre	Number/hectare	2.471
unces	Grams	28.350
unces/acre	Grams/hectare	70.053
ounds	Kilograms	0.454
ounds/acre	Kilograms/hectare	1.121
ounds/gallon	Kilograms/liter	0.120
uare feet	Square meters	0.093
uare feet/acre	Square meters/hectare	0.230
ns	Metric tons	0.907
ns/acre	Metric tons/hectare	2.242

[1]The conversion of board feet and cords to cubic ters can only be approximate; the factors are based an assumed 5.663 board feet (log scale) per cubic ot and a cord with 92 cubic feet of solid material.

[2]To convert °F to °C, use the formula 5/9 (°F-32) $\frac{°F-32}{1.8}$.

Common and Scientific Names of Plants and Animals

Plants

Alder, European	*Alnus glutinosa*
Anthracnose	*Gnomonia leptostyla*
Ash, green	*Fraxinus pennsylvanica*
Ash, white	*Fraxinus americana*
Autumn-olive	*Elaeagnus umbellata*
Basswood, American	*Tilia americana*
Beech, American	*Fagus grandifolia*
Boxelder	*Acer negundo*
Coffeetree, Kentucky	*Gymnocladus dioicus*
Cottonwood, eastern	*Populus deltoides*
Elm, American	*Ulmus americana*
Hackberry	*Celtis occidentalis*
Locust, black	*Robinia pseudoacacia*
Oak, northern red	*Quercus rubra*
Redcedar, eastern	*Juniperus virginiana*
Trumpetcreeper	*Campsis radicans*
Walnut, black	*Juglans nigra*
Willow	*Salix* spp.
Yellow-poplar	*Liriodendron tulipifera*

Animals

Casebearers	*Acrobasis* spp.
Caterpillar, black walnut	*Datana integerrima*
Squirrel, eastern fox	*Sciurus niger*

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key – out of the reach of children and animals – and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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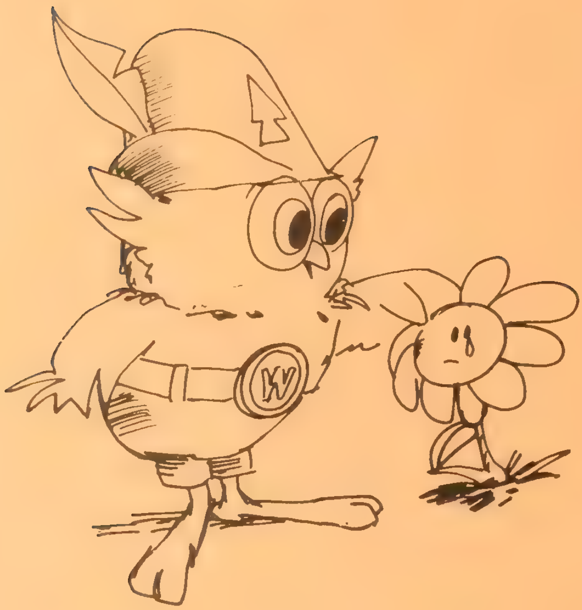

Birds, animals and flowers are dying to tell us...no pollution, please!

manager's handbook for

NORTHERN HARDWOODS IN THE NORTH CENTRAL STATES

ERAL TECHNICAL REPORT NC-39

RTH CENTRAL FOREST EXPERIMENT STATION   FOREST SERVICE   U.S. DEPARTMENT OF AGRICULTURE

Other Manager's Handbooks are:

Jack pine—GTR-NC-32

Red pine—GTR-NC-33

Black spruce—GTR-NC-34

Northern white-cedar—GTR-NC-35

Aspen—GTR-NC-36

Oaks—GTR-NC-37

Black walnut—GTR-NC-38

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FOREWORD

This is one of a series of manager's handbooks for important forest types in the north central States. The purpose of this series is to present the resource manager with the latest and best information available in handling these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. However, ways to modify management practices to maintain or enhance other values are included where sound information is available.

The author has, in certain instances, drawn freely on unpublished information provided by scientists and managers outside his specialty. He is also grateful to the several technical reviewers in the region who made many helpful comments.

The handbooks have a similar format, highlighted by a "Key to Recommendations". Here the manager can find in logical sequence the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbook. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objective. The manager should also apply new research findings as they become available so that the culture of these important forest types can be continually improved.

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NORTHERN HARDWOODS IN THE NORTH CENTRAL STATES

Carl H. Tubbs, *Principal Plant Physiologist*
Marquette, Michigan

orthern hardwoods, broadly defined, cover as h as 100 million acres in the Eastern United es and Canada. They are an important source of ral valuable timber species, and provide esthetic, life, and recreational resources for many people g nearby in eastern and midwestern population ers.

he management situation for northern woods has changed since early marking guides published 20 years ago. Until recently, most of esearch done in the Lake States focused on the vidual tree selection method. So we have the greatest knowledge of, and experience with, this method. But we have started doing more research into even-age practices to increase the number of silvicultural alternatives available. Even-age practices may increase efficiency in harvesting and stand tending, help provide a variety of wildlife habitats, and improve species composition.

In this handbook we attempt to present the best information now available on both even-age and all-age management so the forest manager has the choice of the one that best fits his conditions and management objectives.

SILVICAL HIGHLIGHTS

rthern hardwoods are composed of several t types, and can be split into two groups: types are largely composed of sugar maple and other ax species growing on well-drained sites; and s that are composed of subclimax species ing on less well-drained or excessively drained e In the Lake States both groups would eventually me stands with significant amounts of red e[1] or sugar maple, or beech. (In the Lake States n does not extend beyond eastern Wisconsin the central Upper Peninsula of Michigan.) hern hardwoods merge with boreal forest types e north and central hardwoods in the south.

The major northern hardwood species are generally shallow-rooted, long-lived, and respond to release at advanced ages. The commercially important species range from moderately to very shade tolerant. The long-term ecological trend in northern hardwoods is toward sugar maple, sugar maple-beech, or maple-basswood cover types, which are climax. The most slowly changing type is elm-ash, which may be climax on poorly drained sites; the most rapidly changing types are on the better-drained sites. Partial cutting or similar disturbances normally speed the change toward climax.

The major hardwoods are prolific but sometimes irregular seeders. Maples reproduce easily from seedlings after any overstory disturbance that leaves partial shade; other species such as yellow birch and eastern hemlock require in addition some

[1]*r scientific names of plants and animals, see pndix, p. 27.*

sort of seedbed disturbance for good reproduction (except on wetter sites).

Sprouting ability varies among northern hardwoods. Beech, the elms, basswood, and red maple are prolific sprouters; yellow birch seldom sprouts. Young trees sprout more prolifically than older trees. Only the sprouts of basswood, and seedling and small sapling sprouts (up to 2 inches d.b.h.) of other species, are considered desirable for reproducing northern hardwood stands.

Basswood rates the highest — and sugar map the lowest — in general tree quality (consideri stem straightness, forking, growth rate, an tolerance); other species are intermediate. Epicorm branching — a common cause of poor form — frequent in northern hardwoods that have bee badly suppressed and then heavily released.

MANAGEMENT OBJECTIVES

Northern hardwood tracts can be managed for any one of several objectives, including timber, water, wildlife, or recreation; or for any combination of these. Owners who manage for timber, for example, include those consuming stumpage themselves, or selling stumpage in a variety of markets, for a variety of products and species. Likewise, recreation management can complex and include practices for parks, roadside streamsides, and the protection of wintering de herds. In short, stand conditions, site, and tree si alone do not dictate the techniques to be used; t many possible products or management objectiv must be considered.

DESCRIPTION OF NORTHERN HARDWOOD TYPES

To use this handbook, first select the forest type in the following list that comes closest to the one being considered, and read the description of the type on the page indicated. Then, considering the site, the mix of species, and the economic limitations, decide what your objective in managing the stand will be. And, with help from the type description, decide whether to use even-age or all-age techniques to achieve your management objective. Then turn to the Key to Recommendations on page 6.

Sugar Maple, Sugar Maple-Basswood, Sugar Maple-Yellow Birch

These are the types in which sugar maple tre make up 70 to 75 percent of the stand. In the sug maple-basswood, and sugar maple-yellow bir basswood and yellow birch would comprise percent or more of the stand, respectively. Th types could be managed for any of the us objectives — timber, pulp, wildlife, esthetics.

Selection, shelterwood, or clearcutting can all used to regenerate stands, depending on conditio Selection leads to many-sized stands and results i predominance of tolerant species. Shelterwood a leads to tolerant species; shelterwood with scarifi tion and removal of advance regeneration leads t mixture of moderately tolerant and tolerant speci Where sites are favorable for species other th sugar maple, both shelterwood and selecti procedures will result in moderate numbers

cies other than maples. Shelterwood will be of in concentrating browse and creating overstory nings where wildlife is important. Clearcutting enerally undesirable if timber is the objective. wever, clearcutting is useful for wildlife browse l for converting the stand to less tolerant species he southern and eastern portions of the range of thern hardwoods.

In the Upper Great Lakes area consider options carefully before scarifying or clearcutting on very light soils (sands), very heavy soils (silt or clay loams), or other areas that are prone to invasions by undesirable grass and brush (fig. 1). Such drastic procedures frequently fail to result in regeneration on these sites.

Figure 1.—*Removing overstories before the advance regeneration is large enough may result in grass and brush patches.*

Beech-Sugar Maple

In this type beech makes up 20 percent or more of the stand, and sugar maple most of the remainder. Stands of this type can be managed for the usual objectives, except that in some areas beech is less valuable for timber than sugar maple. However, beech mast is valuable for wildlife.

Light selection cuttings favor beech reproduction; heavy selection cuttings (i.e., leaving saw log stands of only 50 square feet of basal area) discriminates against beech reproduction. In other respects management techniques that apply to the foregoing sugar maple types also apply here.

Aspen-Northern Hardwoods

Typically, aspen predominates in the overstory in this type, while northern hardwoods are invading the understory. Options include: (1) maintaining and managing aspen for timber, pulp, or wildlife by complete clearcutting (Perala 1977); (2) converting to northern hardwoods for timber or wildlife using the shelterwood or selection system; or (3) maintaining a mixture of aspen and northern hardwoods for wildlife or esthetic objectives. To maintain the mixture on the same area, aspen can be interspersed with northern hardwoods in clearcut strips or blocks, while the northern hardwoods are managed as given above.

Paper Birch, Paper Birch-Aspen, Paper Birch-Northern Hardwoods

These types range from pure paper birch to paper birch mixed with aspen, to paper birch mixed with — and converting to — northern hardwoods on the better sites. Stands of these types could be managed for sawtimber and veneer (if the site index is 60 or more), for pulpwood, or for their esthetic appeal.

Where birch and aspen are mixed and the birch site index is less than 60, the stands should be clearcut as in the case of aspen stands (Perala 1977). Progressive strip clearcutting and scarification of sites having a site index of 60 or more will reproduce paper birch on mineral soils.

Red Oak-Northern Hardwoods

This type contains 20 percent or more red oak mixed with other northern hardwood species. Stands of this type could be managed for any of the usual objectives, however, none of the known regeneration methods maintains or increases the amount of oak in the stand. Selection cutting leads to northern hardwoods the fastest. Clearcutting is not recommended.

Hemlock-Northern Hardwoods

Hemlock is a prominent species in this type. Sugar maple is less common; yellow birch, black ash, red maple, and elm are commonly mixed with the hemlock.

Any of the usual objectives could be managed for in stands of this type. To maintain the same composition of hemlock and hardwoods, use the shelterwood method with site preparation. To gradually increase the more tolerant hardwoods reproduce the stand using the selection method. Group selection in combination with individual tree selection appears to increase the proportion of yellow birch in this type.

Lowland Hardwoods

These wet site stands are characterized by varying mixtures of red maple, black ash, yellow birch, and elm; conifers such as balsam, hemlock, spruce, and cedar are usually present. Lowland hardwoods commonly intergrade with swamp conifer types and the hemlock-northern hardwood type. The types are frequently intimately mixed over large areas.

Stands of lowland hardwoods could be managed for any of the usual objectives. If timber is the objective, and species composition and site are relatively good, use individual tree selection. Pockets of hemlock-hardwoods within predominantly lowland hardwood areas should be managed the same way unless wildlife and esthetic appeal are the management objectives. In the latter case regenerate using the shelterwood method with ground preparation to maintain the hemlock.

owland hardwoods are often defective on poorer ter sites. These sites can either be converted to uce or be reproduced using the shelterwood thod.

/hen swamp conifers form the majority of the nd, regenerate by clearcutting strips 1 tree-height vidth if less than 30 square feet of basal area of ifers remains in the strip, and 2 tree-heights in th if more than 30 square feet of basal area ains (Johnston 1977a, 1977b).

Previously Unmanaged Second-Growth — Any Type

ast extensive use of northern hardwood forests e left many stands in relatively poor condition intensive management. These kinds of stands termed "second-growth" by many foresters. y are typically rather even-size, pole-size or ller, with a scattered overstory poorly formed or ctive saw logs. Stands are often primarily sugar maple but may be composed of any mixture of species; some stands have originated mostly from sprouts. Grassy or brushy openings may be common.

Before unmanaged second-growth pole stands (defined here as having less than 50 square feet basal area of saw log-size trees — these at least 10 inches d.b.h.) can be brought under either even-age or all-age management, their quality must be improved. The following improvement scheme is for second-growth stands composed primarily of high-value hardwoods. Aspen and white birch mixtures are considered elsewhere.

Make an initial improvement cut concentrating in the most abundant size class (5 to 9 inches d.b.h.) also removing the most defective and poor quality stems of all sizes. A cut that leaves 80 to 85 square feet (5 inches d.b.h. +) in the residual stand with the major cut in the poles is optimum for most species groups other than hemlock or basswood. Subsequent cuts at 10- to 15-year intervals should aim at an all-size structure for all-age practice (see table 1, p. 19, Appendix) while even-age thinning should lead to an even-sized stand (see figs. 6, 7, 8, p. 20, 21, 22, Appendix).

KEY TO RECOMMENDATIONS

After having read the description of the type being considered, go to the section in this key that best describes the size tree and stocking (*seedling — well-stocked, sapling — well-stocked, pole — well-stocked, sawtimber — well-stocked, any size — understocked*) in the stand being considered. In that section find the statement that best describes the stand, and turn to the recommendation number indicated on page 7. The recommendations also refer you to pages in the *all-age* and *even-age* management sections for details of techniques, or to figures in the appendix. (Note that in the key, the first six recommendations — for seedling and sapling size stands — all recommend *even-age* practices. Not until stands reach pole size should *all-age* practices be considered.)

Seedling — well-stocked
(less than 1.4 inches d.b.h.)

	Recommendation Number
1. Stands without overstories	1
2. Stands with scattered overstories of less than 40 square feet:	
a. Scattered aspen or red maple overstories	3
b. Other overstory species	2

Sapling — well-stocked
(1.5 to 4.5 inches d.b.h.)

1. Stands with yellow birch and/or basswood or red maple sprout clumps	4
2. Stands without sprouts or yellow birch	5
3. Stands with scattered overstories of less than 30 square feet	6

Pole Stands — well-stocked
(4.6 to 9.5 inches d.b.h.)

1. Less than 100 square feet basal area per acre	7
2. More than 100 square feet basal area per acre:	
a. Yellow birch (20 percent or more)	8
b. Hemlock (50 percent or more)	9
c. Northern hardwoods (other than those listed)	10
d. Aspen-northern hardwood	11
e. Paper birch, paper birch-northern hardwoods:	
Less than site index 50	12
Site index 50 to 60	13
Site index 60 and better	14
f. Sugar maple-basswood	15
g. Sugar maple-beech	16

Saw Log Stands — well-stocked
(9.6 inches d.b.h. and up)

1. Northern hardwoods (red oak-northern hardwoods, lowland hardwoods, sugar maple types):	
a. Less than 80 square feet saw log basal area	17
b. More than 80 square feet	18
2. Sugar maple-beech	19
3. Paper birch site index 60 or better	20
4. Paper birch-northern hardwoods	21
5. Hemlock, hemlock-hardwoods	22

Any size — understocked

Less than 40 square feet of poles or saw logs or less than 1,000 well-spaced saplings or 5,000 well-spaced seedlings	23

LIST OF RECOMMENDATIONS— ALL-AGE AND EVEN-AGE

. Do nothing now; review when stand reaches sapling size.

. When reproduction reaches 4 feet in height and is 50 percent or better stocked with desirable species, remove or kill the overstory (p. 11).

. When reproduction reaches sapling size, remove overstory, poison red maple stumps if necessary (p. 10).

. Thin yellow birch (p. 10) and sprout clumps (p. 10).

. Do nothing now; review when stand reaches pole size.

. Remove or kill overstory.

. If stands are to be managed under the all-age system, do nothing until stands reach 100 square feet basal area. If stands are to be managed under even-age system, follow even-age stocking levels (Appendix, p. 20).

. To encourage yellow birch:
  a. In even-age stands do timber stand improvement work (TSI), releasing birch and discriminating against sugar maple (p. 10).
  b. If all-age stands are to be developed, do TSI, favoring any high-quality stem of any desirable species, especially yellow birch of any size (p. 9).

. To encourage hemlock do TSI, following even-age stocking levels (fig. 8, Appendix), discriminate against sugar maple first; then other hardwoods (p. 10).

To develop hardwood stands do TSI when stands reach 100 square feet (4.6 inches d.b.h. and over) favoring any high quality stem of desirable species; use either even-age or all-age techniques (p. 9, 10).

1. To maintain even-age stands do TSI, using the even-age stocking guide (fig. 6, Appendix).
To develop all-age stands do TSI when stands reach 100 square feet, using all-age techniques (p. 9).

1. a. To maintain aspen, clearcut (Perala 1977).
  b. If the understory is northern hardwood, convert to northern hardwoods by making partial cuts (p. 10 and p. 12).
  c. If the stand is a mixture of northern hardwoods and aspen poles, convert to northern hardwoods (p. 10 or fig. 6, Appendix); discriminate against aspen.

1. a. Clearcut before age 60 (p. 13).
  b. If understories of desirable tolerant species are present, make partial cuts (p. 10).

13. Same as 12 except that one thinning is possible (p. 13).

14. Thin from below if markets are available. Discriminate against other hardwoods to maintain paper birch (p. 13); favor other hardwoods to convert to northern hardwoods (p. 10).

15. In stands with 50 percent or more basswood, cut when stands reach about 130 square feet or over (p. 11 or fig. 7, Appendix). In stands with less than 50 percent basswood, cut when stands reach 100 square feet or over (p. 9 or fig. 6, Appendix).

16. To discriminate against beech, reduce residual basal area to 60 square feet cutting as much beech as possible (p. 9 or fig. 6). To maintain or increase beech, leave residual stands with 85 square feet or more (p. 9 or fig. 6, Appendix).

17. Reexamine in 10 years if even-age (fig. 6, Appendix) or follow all-age guides (p. 9).

18. To maintain or develop even-age stands of tolerant hardwoods, thin according to even-age stocking guides (fig. 6 and 7, Appendix) and regenerate using shelterwood techniques (p. 11). To maintain or develop all-age stands of tolerant species, make selection cuts at about 10-year intervals (p. 9).

19. To reduce beech stocking, make selection cuts to 50 square feet of basal area per acre in saw log-size stems cutting beech whenever possible.

20. To maintain paper birch, strip clearcut with site preparation (p. 13).

21. To convert to northern hardwoods, make partial cuts (p. 10, 11).

22. a. To maintain hemlock, thin until rotation age following even-age techniques (fig. 8, Appendix) then use shelterwood techniques with site preparation and artificial seeding to regenerate (p. 12).
  b. To maintain yellow birch, thin until rotation age using even-age techniques, discriminate against sugar maple (fig. 6, Appendix) use shelterwood techniques with site preparation (p. 12).
  c. To convert to even-age tolerant hardwoods, thin to northern hardwood standards (fig. 6, Appendix) use shelterwood without site preparation (p. 11).
  d. To convert to all-age stands of northern hardwoods, use selection techniques (p. 9).

23. Do nothing if hardwood or wildlife production is the goal. Convert to appropriate conifer if immediate production is required (p. 13).

Developing Balanced Size Classes

All-age silviculture is a good choice if tolerant species are expected to dominate the stand (fig. 2). Individual tree selection is the recommended cutting method; group selection is sometimes used in conjunction with individual selection.

To develop balanced size classes for good growth and highest-quality yields consistent with management goals, use the following procedure.

Stocking Level

Try to maintain stocking at 70 square feet per acre in trees 10 inches d.b.h. and over when cutting cycle does not exceed 15 years. This is the optimum stocking of northern hardwoods for maximum board-feet growth of high-quality saw logs on average sites. For timber management do not [illegible] below 50 square feet per acre or above about [illegible] square feet per acre.

Maximum Tree Size

Cut trees when they are financially mature or [illegible] times when removal will benefit the surroundi[illegible] stand, or when a combination of these consideratio[illegible] seems optimum. Set goals for stocking level a[illegible] tree size for all cutting units regardless of th[illegible] present size-class distribution.

Size-Class Distribution

Use a tested, empirical size-class distribut[illegible] (table 1, Appendix) as a marking guide to maxim[illegible] board-foot growth, or calculate a size-class distri[illegible] tion for this purpose (see Appendix, p. 19). (If [illegible] calculate a size-class distribution, note that la[illegible]

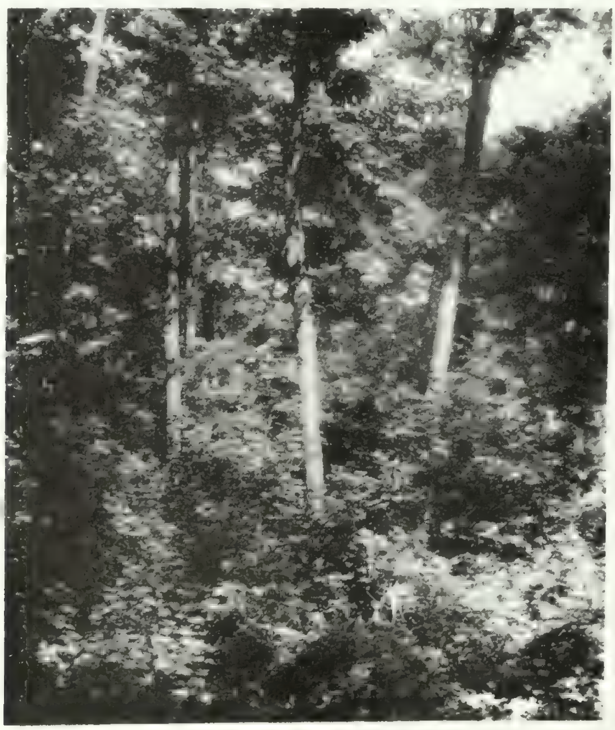

Figure 2.—*Selection stand of sugar maple and associated species. After one cut the stand resembles a shelterwood; several periodic cuts are necessary to develop good size class structure.*

tios between size classes lead to many small trees, hile small ratios lead to greater numbers of large ees.)

Size-class distributions are guidelines only; the ze classes can be rather broad. In general in un-gulated stands, the heaviest cut will be in the ver-abundant size classes, while in regulated ands some trees will be cut in all the merchantable ze classes. Experience has shown that 4- or 5-inch b.h. classes are precise enough for field work. The itial development of stands understocked with w logs requires only two classes (saw logs and les).

utting Cycle

Choose cutting cycles so that stands are cut when ey reach 90 to 100 square feet. Normally this ill occur between 8 and 12 years after the stand as been cut to not less than 60 to 70 square feet of sidual basal area per acre. In stands overstocked ith poles, these figures apply to trees 5 inches b.h. and up. In saw log stands they apply to all ees 10 inches d.b.h. and up.

The cutting cycle length in years divided into the umber of acres of land equals the annual cutting ea.

Regenerating and Treating All-Age Stands

aw Log Stands: At Least 50 Square Feet asal Area; Trees 9.6 Inches d.b.h. or More

Harvest mature timber. Do not reduce saw logs elow 50 square feet per acre or leave above 90 quare feet per acre. (These figures may be exceeded n very good sites or where short cutting cycles are ossible or where significant numbers of conifers or mall-crowned hardwoods such as basswood are resent.)

Cut in all merchantable size classes in regulated tands. Cut trees first that may not survive the utting cycle, followed by defective trees (table 2, Appendix), then trees whose economic potential has been realized. In all removals consider the effects on the remaining trees. In deficient size classes of unregulated stands, remove only those trees that have no potential for further economic growth or are interfering with the growth of a better tree (p. 24, Appendix). Cutting in the sapling class is not necessary; cutting in the pole class should be for improvement or occasionally thinning where large groups of overstory trees were removed.

Hemlock-hardwood.—In stands overstocked with saw logs first cut back to 100 to 150 square feet of basal area per acre. A salvage should be planned within 5 years after the first cut in overmature stands. Subsequent cutting of these stands should reduce the stand to 80 square feet of residual basal area per acre in trees 10 inches and larger. The cutting cycle should average about 10 years.

Pole Stands: Less Than 50 Square Feet Basal Area Per Acre; Trees 4.6 to 9.5 Inches d.b.h.

The cut should normally be concentrated in the pole class. Only the poorest saw logs should be cut. Stands should be entered when a sufficient number of trees have acceptable merchantable lengths. The amount of cutting in the pole size class is keyed to the amount of merchantable saw log overstory. This is necessary to obtain the largest amount of board-foot growth in the shortest time and to quickly develop size-class distributions capable of sustained yields of high-value saw log products.

Use the guidelines in the tabulation below to maximize board-foot production as the stand develops. Reducing pole components of stands to the smaller of the basal areas will increase individual tree growth rates; choosing the higher figure will aid tree quality but reduce individual tree growth rates.

If saw log (10 inches d.b.h.) basal area is:	*Leave indicated basal area in poles 5 to 9 inches d.b.h.*
(Square feet per acre)	
0	60 to 85
20	40 to 65
40	30 to 50
50	20 to 40

It should be emphasized that as much of the merchantable saw log overstory should be kept as possible.

Initially remove saw log-sized trees only because of risk or cull. Board-foot growth increases as the saw log basal area increases; board-foot growth increases sharply when the pole class is thinned if merchantable saw logs are not removed. For example, a stand containing 20 square feet of saw logs and 70 square feet of poles may grow as much as 200 board feet per acre, and in 10 years the saw log component will increase to about 40 square feet. If the original 20 square feet of saw logs are removed, the growth will be less than 100 boar[d] feet per acre. After the saw log component reach[es] 60 square feet or over, then saw log growth can b[e] harvested without reducing future yields in man[y] cases.

Aspen or Paper birch-Northern hardwoods.—Pap[er] birch or aspen on northern hardwood sites may [be] converted to northern hardwoods by partial cuttin[g]. The partial cutting should follow northern har[d]wood guides for total stocking, i.e., leave 70 to [...] square feet per acre in trees 4.6 inches d.b.h. an[d] larger, discriminating against white birch or aspe[n].

EVEN-AGE SILVICULTURE

Even-age silviculture can be used for both shade tolerant and those tree species less tolerant of shade; reproduction methods include shelterwood and clearcutting. The former method can be used with site preparation to improve the proportion of moderately tolerant species and to improve harvesting efficiency; the latter method for the reproduction of intolerant species.

Because less is known about even-age procedures, recommendations are more tentative than for all-age procedures. Optimum stocking, rotation, and thinning schedules have not been studied for all species. Rotation may be as short as 50 years for fiber products or as long as 200 years for eastern hemlock when esthetics is an important management goal. Rotation lengths of red and sugar maple and yellow birch can vary from 90 to 120 years depending on site and the intensity of management.

Tending Even-Age Stands

Seedling-Sapling Stands

The objective is to maintain composition and remove overstory competition.

First, remove or kill scattered overtopping trees, both cull and sound. Yellow birch saplings should be crown-released between 10 and 20 years of age. [...] trees whose crowns are within 5 feet but not m[ore] than 10 feet of the crown of the birch. Trees t[o be] released should be at least codominant and unfork[ed].

Sapling-size basswood and red maple spr[out] clumps should be thinned to two or three of [the] straightest, least-defective stems. Release of sapli[ngs] of other hardwood species ordinarily will not [be] practical.

Pole Stands

Markers have several silvicultural objectives [to] keep in mind. Remove trees with little growth [or] grade potential to upgrade the stand and red[uce] mortality, and release trees with good potentia[l to] increase growth without substantial quality l[oss]. Keep stocking that will maintain productivity.

Begin releasing pole stands when clear leng[ths] are adequate for management purposes (norm[ally] 1-1/2 logs in height). First release trees that are [well] formed and have no forks or strong forks. Tr[ees] whose crowns are small (usually weak codomina[nts] or intermediates) must receive only light cr[own] release (remove adjacent trees whose crowns [are] within 5 feet) or selection thinning (remove 1 or [...] the most competitive trees). Codominant [and] dominant trees of good form and foliage den[sity] may receive a heavier release. For the first thinn[...]

elease only crop trees — those whose potential for rowth and quality is high.

In northern hardwoods, do not reduce the basal ea of trees 4.6 inches d.b.h. and over to less than) square feet, or leave more than 85 square feet in ees 4.6 inches d.b.h. and over unless basswood or emlock are present (figs. 6, 7, 8, Appendix). White rch on good sites should be thinned from below imarily, and crown cover of the main stand ould be as continuous as possible. White birch obably will not respond to thinning past age 60. emlock or basswood pole stands should be thinned om below following even-age stocking levels (figs. 8, Appendix). Unless planned for wildlife purposes, oid large openings which may result in excessive anching on border trees.

Natural pruning is usually efficient enough to move nearly all the limbs from the butt log in ands with 60 square feet or more; most live limbs pole-sized (5 to 9 inches d.b.h.) trees are in the cond log.

Do not prune until 3 years after release to reduce icormic sprouting. Unreleased trees should not be uned. Trees to be pruned should be in the dominant d codominant crown classes and should be tential crop trees. Discoloration and decay result- g from artificial pruning of northern hardwoods e not important and may even be less than that curring after natural pruning.

Wound healing time is shortened by pruning nbs close to the bole. (Wound healing is delayed to 3 years for each 1/4 inch of branch stub left.) ounds heal fastest on rapidly growing trees with od crown development. As a rule of thumb, a dial growth equal to the width of the wound is quired to completely heal the wound. White ash d American elm heal the fastest, followed by gar maple and yellow birch. Basswood is variable. nder current economic conditions, trees under 6 or inches d.b.h. should usually not be pruned since mpound interest costs can equal or overtake the turns from pruning trees smaller than this before rvest. It is economically questionable to prune anches in the second log with the equipment rrently available since costs are high and pruning difficult to perform correctly at this height.

Saw Log Stands

First remove culls, trees with weak forks, partially windthrown or leaning trees, those with badly cankered areas, trees with dieback or black bark stemming from sapsucker attack, and trees with other characteristics indicating serious loss of merchantability (table 2, Appendix) or mortality before the next cutting cycle. Remove mature and financially mature trees (generally those with no possibility of attaining veneer or saw log grades 1 or 2) and those not needed for silvicultural purposes. Next remove trees interfering with the growth of those with higher grade potential. Avoid large openings which may reduce quality of border trees.

In northern hardwood stands with less than 20 percent conifers or basswood, the stocking level of the main stand should not be reduced below 80 square feet per acre and should not exceed 120 square feet per acre.

Stands containing appreciable numbers of bass- wood, or hemlock, or other conifers can be thinned to about 70 percent crown cover or to basal area levels suggested in figures 7 and 8 in the Appendix.

Regenerating Even-Age Stands

Two-Cut Shelterwood For Tolerant Species

1. Select stands that are moderately well stocked with advanced regeneration of desirable species. Stands should average *at least* 8 inches d.b.h. If the stocking of advanced reproduction is sparse, consider the three-cut shelterwood outlined below.

2. Marking *must* be from below. Leave 60 percent crown cover at regular spacing. *All* trees left must be considered part of the residual crown cover.

3. Initial logging should be done only when the ground is snow-covered to minimize seedling loss.

4. Remove the overstory after the reproduction attains a height of 3 to 4 feet. A minimum of 5,000 well-spaced seedlings per acre or 1,000 well-spaced saplings per acre (2- to 4-inch d.b.h. class) are present. Log when the ground is snow-covered, removing all stems. Lopping of slash should be minimized and restricted to recreational or access areas.

5. Space "leave" trees as uniformly as possible. Crown areas and spacing per acre may be calculated by using the crown area per tree (table 3, Appendix).

Modifications to favor yellow birch. (1) Choose cool, moist (hemlock-hardwood) sites for regenerating yellow birch (fig. 3). (2) Discriminate against mature sugar maple in the residual overstory during marking. Leave no more than 70 percent, nor less than 30 percent, crown cover of the most vigorous trees. The lower of the residual crown covers can be used where scarification is done on well-drained soils. Higher basal areas should be used when fire is prescribed or on wetter sites that are not scarified. (3) Scarify 50 percent or more of the surface area after leaf fall but prior to logging. (Scarification in saw log stands often is most easily done before logging debris litters the ground.) I not scarify soils classed as "sands". Scarificati should aim at mixing the humus and mineral s and destroying advance regeneration. Kill advanc regeneration prior to cutting on sites too difficult scarify. (4) Make the first cutting during a modera or better seed year, or direct seed before midwint at a rate of at least 1/4 pound per acre on t scarified area.

Modifications for converting Aspen-Northe hardwoods to Northern hardwoods.—Follow t shelterwood recommendations for tolera hardwoods. Allow at least 5 years between the fir removal and the first shelterwood cut. The purp of the overstory is to aid in the establishment of t northern hardwood understory and to suppre aspen sprouts resulting from the first cut.

Figure 3.—*Yellow birch reproduction under a shelterwood overstory.*

'hree-Cut Shelterwood

Three-cut shelterwoods may be used where sthetics are a management objective, where dvance regeneration is sparse, or where serious rass-brush invasion is probable. Bring the residual tand to 50 percent crown cover in two cuts as ollows:

In mature saw log stands of most hardwoods, the rst cut from below should leave 90 to 100 square eet of residual basal area in trees over 9.6 inches b.h. or about 80 percent crown cover. When the egeneration is about 4 feet in height (5 to 10 years) second cut to about 50 percent crown cover will artially release the regeneration.

The final removal should be made before re-eneration reaches 15 feet in height.

'learcutting

Clearcutting to provide new even-age stands of iost northern hardwood species from seed is enerally the least desirable of the regeneration ethods in the Upper Great Lakes area. However, earcutting has application in some situations. here the major high-value tolerant species are herently poorly formed, for example, and the only esirable species are intolerant, clearcutting or earcutting and planting may be the only feasible ternatives.

Clearcutting by itself is not sufficient to convert ands to more desirable species; other measures ust be used in addition to remove maple reproduc-on. If fire is chosen, burn in the spring during afout and before cutting. Or, scarify by whatever eans available; or use a registered herbicide. (see esticide Precautionary Statement, p. 28).

Converting to conifers. If conifers are planted, e size of the clearcut has no stringent silvicultural nitations except that areas which may be reseeded sugar maple, or where hardwood sprouting curs, should be weeded during the first 5 years.

Maintaining or converting to white birch.—Clear-cutting to regenerate white birch may need to be supplemented by treatment of advance regeneration, depending on the site. First determine the site index of stands to be converted to white birch by using site index curves for old stands (fig. 9, Appendix), soil measurements for young stands, or both. Because sites vary considerably in short distances, manageable units should be outlined, and the most common site index within the unit should be considered to be the site index for the whole unit.

Sites with a site index below 50 generally have poor surface drainage or are on steep slopes, and have silt plus clay percentages less than 10.5. Clearcut paper birch for pulpwood-size products before stands are 60 years old. Regeneration may be primarily by sprouts. Stands older than 60 years will sprout poorly.

Stands with site index 50 to 59 should be managed the same as those below site index 50. Total value yield can be increased by making a light thinning from below when the stand is about 50 years old. If the stand is thinned, the rotation age can be increased to about 70 years. If it is not thinned, treat the same as stands below site index 50.

Stands with a site index of 60 and better have silt plus clay percents greater than 10.5 in the top 6 inches of mineral soil; surface drainage is usually medium to good. Mottling in the upper 4 feet of soil also indicates a good site. Manage stands on these sites for saw logs and veneer. Pure stands can be thinned for pulpwood at age 40 to 50 years. Thinning should primarily be from below. Avoid creating large openings in the crown canopy. Clear-cut when the stand is about 80 to 90 years old. Strips should be clearcut about a chain in width or not over tree height at the maximum. Progressive strips are best. Regenerate by scarification. Openings should be less than 300 feet in diameter if regenera-tion is by natural seeding. If larger clearcuts are necessary, leave seed trees or use supplemental seeding.

OTHER RESOURCES

Wildlife and Water

Northern hardwood types harbor numerous kinds of birds and animals, both game and nongame. In northern hardwoods as in other forest types, diversity of species and size class leads to a wide representation of animals and birds. Normal forest management can produce sufficient diversity to suit many wildlife species. In some cases, however, a single tree species must be favored because of its special benefit to wildlife.

In areas of deep snow and intense cold, coniferous species provide essential cover for white-tailed deer. In some portions of the Lake States, for example, eastern hemlock provides a significant amount of cover and browse so that the regeneration and maintenance of this species is an important part of management. Hemlock is a long-lived, very tolerant species that requires mineral soil seedbeds for regeneration. The same general procedures used for regeneration of yellow birch can be used for hemlock, except that hemlock should be seeded. It is necessary to seed this species in the fall or stratify seed artificially for 90 days before spring seeding. Because of the long life of hemlock, long rotations and small annual cutting areas are possible.

Where tolerant northern hardwoods border conifer swamp deer yarding areas, the amount of browse can be increased by increasing the frequency of cut and reducing residual stocking levels. Where even-age management is used, a three-cut shelterwood can be employed to increase the length of time that browse is available.

Some rules of thumb for management of browse for wildlife are: selection cutting produces small amounts of browse per acre (fig. 4) and few plant species; clearcutting produces a large amount of browse per acre over a short period of time and relatively many plant species, but the requirements for producing good timber are frequently not met; shelterwood produces as much browse as clearcutting and meets timber production requirements but encourages fewer plant species.

A forest manager need not always modify practices in northern hardwoods to increase wildlife browse or shelter if other forest types that border or are interspersed with the northern hardwoods can provide these wildlife requirements.

Extensive heavy cutting in the past has resulted in large, unbroken areas of pole-size northern hardwoods whose understories are barren and poor habitat for birds and animals. Although small openings usually revegetate quickly and lose value for wildlife, their life can be extended to 20 or 30 years by: (1) cutting them in stands 50 years old or less where there is little or no advanced reproduction; (2) cutting them on either excessively well drained or poorly drained soils, or on soils that are shallow or in frost pockets. Openings should be at least an acre in size, not more than 10, and irregularly shaped.

Northern hardwoods frequently border streams and lakes where they may influence water quality, water temperatures, and fish populations. Silvicultural practices to enhance or preserve these features probably do not vary from those used in other forest types.

Figure 4.—*Unmanaged old growth northern hardwood forest makes poor habitat for deer.*

Recreation and Esthetics

3ig trees near campgrounds, roads, trails, and oher areas of greater than average visibility, are oen esthetically pleasing to recreationists. To mnage for them, the normal selection techniques intolerant hardwoods may be modified by increasing nximum tree size and reducing the q factor (see p 19, Appendix). The same objective may be otained by increasing the residual stocking to 9 square feet of basal area per acre and reducing te q factor to 1.1. The first case (increasing tee size) may require frequent removal of cull tees and timber loss through rots, stains, and mortality. In the second case (increasing density) te trees would be relatively rot free and would povide a reasonable timber harvest. In both cases ctting cycles should be reduced to 5 to 8 years from te 10 to 15 years normally used. Both methods will poduce large diameter timber stands relatively free c undergrowth.

Denser stands are generally more pleasing to the ee than open ones. For this reason, under even-age management, the rotation should be lengthened to increase tree size. Three or more cuts may be used to accomplish regeneration by shelterwood, instead of two.

The fall colors of northern hardwoods are desirable. The most colorful species is red maple. This species is most easily regenerated by coppicing. Younger trees are the most vigorous sprouters; very old trees are not likely to reproduce well. American beech has the least colorful foliage of the species and might be discriminated against if foliar color is the primary objective. On the other hand, the light grey trunks are pleasing to some people.

White birch is obviously a beautiful tree for many forest visitors. It can be most easily regenerated by coppicing before age 60.

Planting of northern species in campgrounds and other recreational areas should follow shade tree practice. Eastern hemlock seems to be the species most sensitive to compaction, fires, and wounding. Hardwoods are generally less sensitive to damage common to these areas.

DAMAGING AGENTS

Logging

Logging damage to the stems and roots of residual tees increases with the size of the skidding equipment and the length of the load. Rot following dmage progresses fastest in yellow birch and owest in sugar maple. In both species, rot from younds less than 50 square inches and less than 10 years old will not cause serious loss. Experience sows that logging damage can be held to acceptable levels by good supervision and training of loggers.

Follow these guides to minimize loss from damage roots and stems.

1. Apply log grading rules to the standing damaged ees and determine which trees will decrease in ade within 10 years. Harvest these trees.

2. In the first cut after wounding (usually about 0 years), harvest all trees with stem wounds larger an 50 square inches if possible.

3. Also in the first cut after wounding, harvest if possible all yellow birch (but not sugar maple) with root wounds that are larger than 50 square inches, within 4 feet of the stem, and in contact with the soil.

4. In subsequent cuts continue to remove the wounded trees still remaining, concentrating on those with the oldest and largest unhealed wounds.

5. When thinning cuts are made with large equipment (such as mechanical fellers) in young stands, clearcut access strips wide enough for equipment to maneuver without bumping trees. The width of strips should not exceed the average crown diameter of the main stand by more than 2 feet or so.

Markers and loggers should try to avoid damaging the crowns and stems of uncut poles and small saw logs. Damage to more than a quarter of the crown may reduce growth, stimulate epicormic branching, and promote both rot and stain.

Although damage to seedlings and saplings in all-age practice often seems extensive, it has no silvicultural significance. In even-age practice, make preparatory cuts in winter before final harvest. Damage to reproduction during winter logging is less than in summer when reproduction may be uprooted. Although slash lopping is often desirable to improve the appearance of a cut-over stand, it tends to inhibit development of regeneration.

Animals and Birds

Damage to reproduction by white-tailed deer and snowshoe hare is not usually significant in managed stands. The changes in form that do result from browsing are corrected in a short time in managed stands. Care should be taken to avoid browsing by farm animals, however. They can cause substantial damage.

Sapsucker feeding in yellow birch crowns reduces growth and may cause top breakage or mortality. Sapsucker feeding on sugar maple stems results in discoloration of the wood and causes a quality degrade if severe. To avoid having sapsuckers transfer feeding to another — perhaps more valuable — tree, leave poor quality trees that they have been feeding on. However, feeding trees that contain high quality logs should be removed promptly to prevent degrade. Sugar maple feeding trees can be distinguished at a distance by patches of black bark discolored by the dark fungi that develop on the sap from sapsucker wounds.

Weather

Wind and ice glaze sometimes permanently bend small trees in even-aged stands. Pole stands, especially ones that have been heavily released, are sometimes damaged when wind and glaze break forks from the trees (fig. 5). In marking to release, favor trees that have strong forks or no forks at all, especially in areas prone to high winds and frequent glaze storms.

Sunscald is sporadic and infrequent in northern hardwoods. Young yellow birch and sugar maple, especially in even-age stands, are most prone to damage. Frost cracking can be a serious cause of degrade and cull in sugar maple in areas such as northern Minnesota. Prolonged drought sometimes results in the death of eastern hemlock.

Figure 5.—*Heavily released forked poles are liable to break at the fork under heavy glaze loads or high winds.*

Insects and Diseases

Most important northern hardwood species are not significantly affected by insect attack. Occasionally an attack coupled with stress caused by unusual climatic conditions can cause serious losses in small areas.

The maple borer may cause degrade or indirectly cause breakage; trees with extensive borer galleries should be marked for cutting. Various bud miners cause forking of young sugar maple, but in dense stands the resulting forks will correct themselves.

The Dutch elm disease is a serious cause of mortality among elm species. Once established, the disease moves rapidly along drainage ways — more slowly in the uplands where elm occurs as scattered individuals. To avoid loss of volume and value, discriminate against elm; remove the higher value stems first. In bottomlands and drainages where elm is a major species, it is not worthwhile to attempt holding a partial overstory to develop a stand of advance reproduction because the disease moves too rapidly.

A number of canker diseases affect northern hardwoods. Yellow birch stems that become infected by Nectria canker should be removed. Diaporthe canker is a fatal disease of slowly growing yellow birch seedlings. Eutypella cankers on sugar maple weaken the stem and reduce merchantability. Sugar maple stems with large cankers should be removed. Trees with small cankers will survive for many decades and put on much usable wood despite the canker.

Organisms that cause rot and stain, and sapstreak, a wilt disease of sugar maple, gain entry through damaged roots, stems, and branches. Reduce losses from these agents by removing high risk trees, keeping rotations less than 120 years, and avoiding logging damage.

Diebacks have not normally affected growth or merchantability of hardwoods. A large number of causal agents apparently can be involved. Climatic conditions, such as prolonged drought or severe growing season frosts, animals, such as porcupines or sapsuckers, and occasionally insects, may be locally important, however.

Fire

Serious wildfires are rare in the northern hardwood types. Spring ground fires can kill most reproduction-sized trees while reproduction damaged in fall ground fires resprouts the following spring. Repeated ground fires kill larger saplings and poles while hot slash fires kill saw log-sized trees.

APPENDIX

Table 1.—*Desirable stocking per acre for good continuous growth*

D.b.h.	Desirable stand after cutting: Trees	Desirable stand after cutting: Basal area
Inches	*Number*	*Square feet*
2	118	2.6
3	53	2.6
4	31	2.7
Subtotal	202	8
5	21	2.9
6	15	2.9
7	12	3.2
8	9	3.1
9	8	3.5
Subtotal	65	16
10	7	3.8
11	6	4.0
12	5	3.9
13	5	4.6
14	5	5.3
Subtotal	28	22
15	4	4.9
16	4	5.6
17	3	4.7
18	3	5.3
19	3	5.9
Subtotal	17	26
20	2	4.4
21	2	4.8
22	2	5.3
23	1	2.9
24	1	3.1
Subtotal	8	20
TOTAL	320	92

Sample Calculation of All-Age Size Class Distribution

The stand objective is 85 square feet of basal area in trees 5 inches d.b.h. and over; the maximum tree size is 24 inches d.b.h.; the data is needed in 2-inch size classes and the ratio between classes (q factor) is 1.3.

D.B.H.	*Ratio* q^n	×	*Tree Basal area*	=	*Coefficient (k)*	*Number of trees*
24	—		3.14		3.14	2.5
22	1.3		2.64		3.43	3.3
20	1.69		2.18		3.68	4.1
18	2.2		1.77		3.89	5.3
16	2.85		1.40		3.99	6.9
14	3.71		0.07		3.96	9.0
12	4.82		0.79		3.80	11.7
10	6.27		0.55		3.44	15.2
8	8.15		0.35		2.85	19.8
6	10.6		0.20		2.12	25.7
				Σk =	34.30	

34.3n = 85 square feet
n = 2.5 trees in the 24-inch class
(2.5) (1.3) = 3.29 trees in the 22-inch class
(3.29) (1.3) = 4.1 trees in the 20-inch class

For other classes, other ratios must be used, i.e., for 5-inch classes 1.9 is about equivalent to 1.3 for 2-inch classes. Coefficients (Σk) for different size class distribution and maximum tree size of 24 inches d.b.h. are: q = 1.1 is 18.5; q = 1.2 is 24.8; q = 1.3 is 34.3; q = 1.4 is 48.09; q = 1.5 is 68.2.

These coefficients divided into any basal area equal the number of trees in the 24-inch class.

Stocking Levels for Even-Age Practice

There have been few tests of the effect of growing stock levels on growth in even-age northern hardwoods in the Lake States. The levels illustrated (figs. 6, 7, 8) were primarily calculated from average growing space requirements. Consequently, the levels are reasonable for good growth and quality, but may not be optimal.

Northern Hardwood (fig. 6)

This curve was developed from sugar maple, white ash, and yellow birch data which seem to represent average conditions for hardwood species other than basswood. The average stocking shown may be conservative for the larger size classes and exceptionally even-sized stands. To preserve individual tree quality, reductions in residual stocking cannot fall below 80 percent of the average. For the same reason, stands containing conifers or small-crowned hardwoods such as basswood should have higher residual stocking.

Northern Hardwood-Basswood (fig. 7)

Basswood trees generally have narrow crowns in relation to stem diameter and stands containing appreciable amounts of this species can hold high basal area stocking compared to other hardwood species.

Stands with less than 20 percent basswood should be treated as other northern hardwood species. Stands with 20 to 49 percent basswood should have higher residual basal area levels — the effect of differing growing space requirements. Stands containing 50 percent or more of basswood can be stocked at higher levels, but residual stocking over 120 probably will not add to net growth very rapidly.

Hemlock-Hardwoods (fig. 8)

The growing space requirements of hemlock and other conifers found in northern hardwood stands are less than basswood, so that residual stocking can be high, although high levels will probably not permit optimum growth. In hemlock stands the economic value of knot-free lumber is somewhat less than in hardwood stands, so a greater range of stocking levels is possible. Residual stocking may be held high for short cutting cycles to prevent unwanted hardwood encroachment and to enhance esthetics, or stands may be cut more heavily to stimulate growth.

Stands of high value hardwoods containing substantial amounts of hemlock should be marked to reflect the effect the hemlock has on the higher value hardwoods, i.e., stands containing more than 20 percent hemlock or other conifers should be marked in proportion to the amount of hemlock to be left.

Because of the great variation in age, soils, cut and composition of hemlock stands, foresters should make use of local observations, if possible, in prescribing treatments.

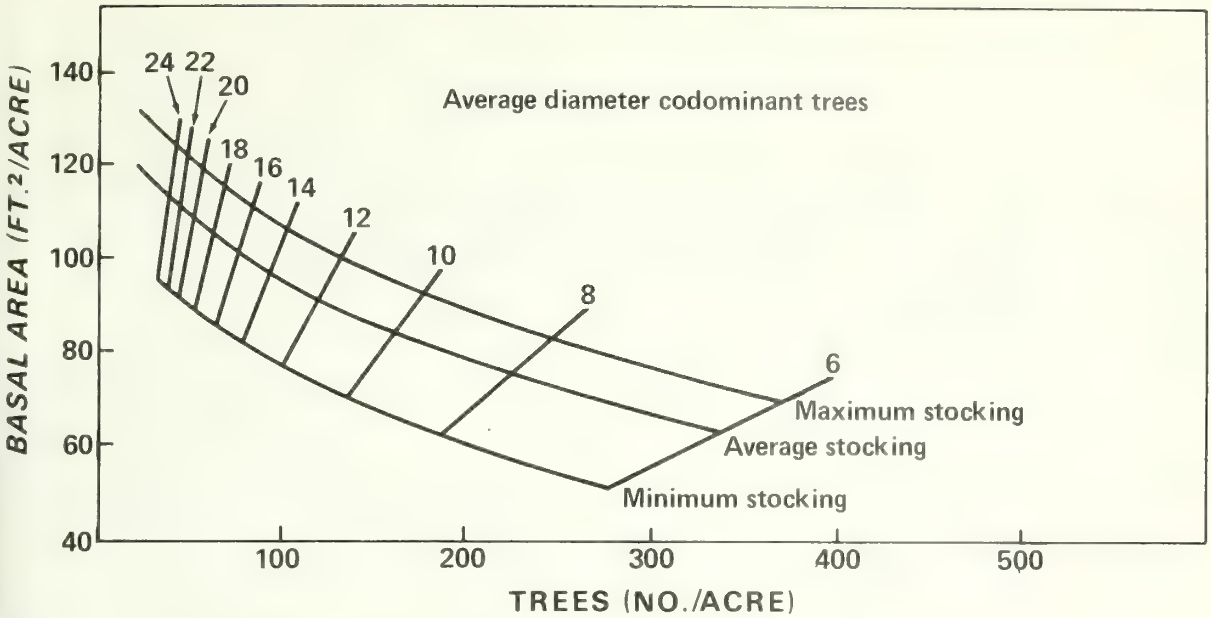

Figure 6.—*Stocking levels for northern hardwood stands containing less than 20 percent conifers or basswood by basal area, and number of trees per acre for specified diameter classes.*

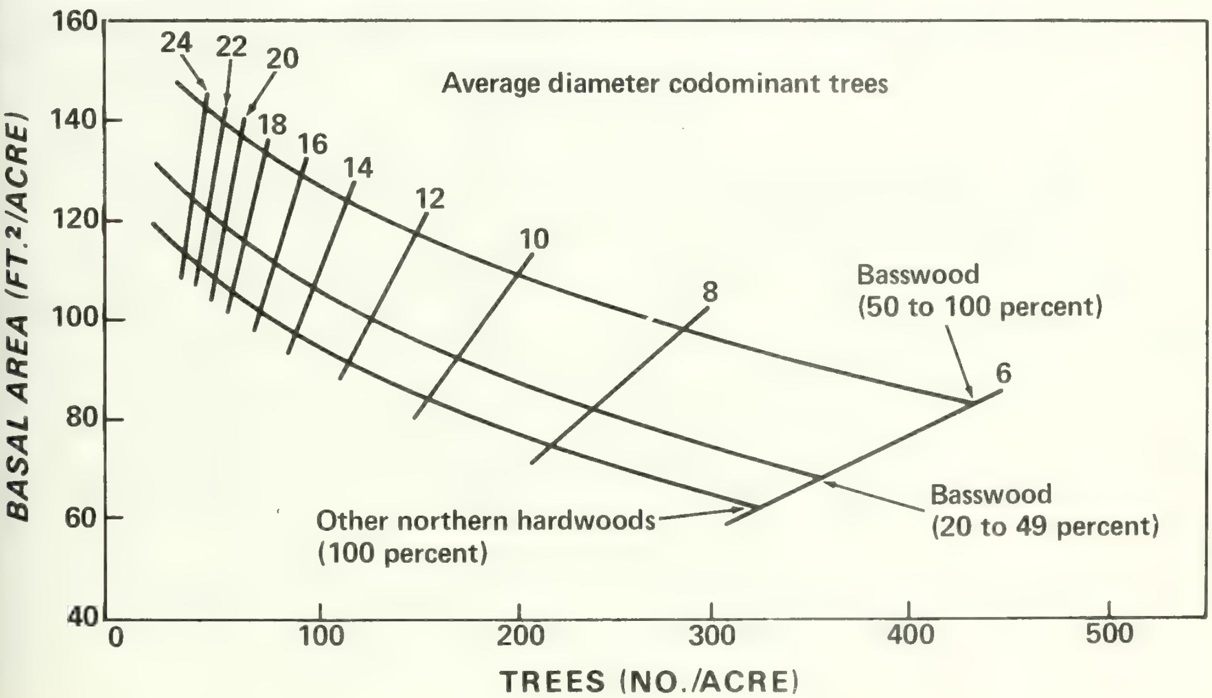

Figure 7.—*Stocking levels for even-age northern hardwood basswood stands in the Lake States by basal area and number of trees per acre for specified diameter classes and certain percentages of basswood and other northern hardwoods.*

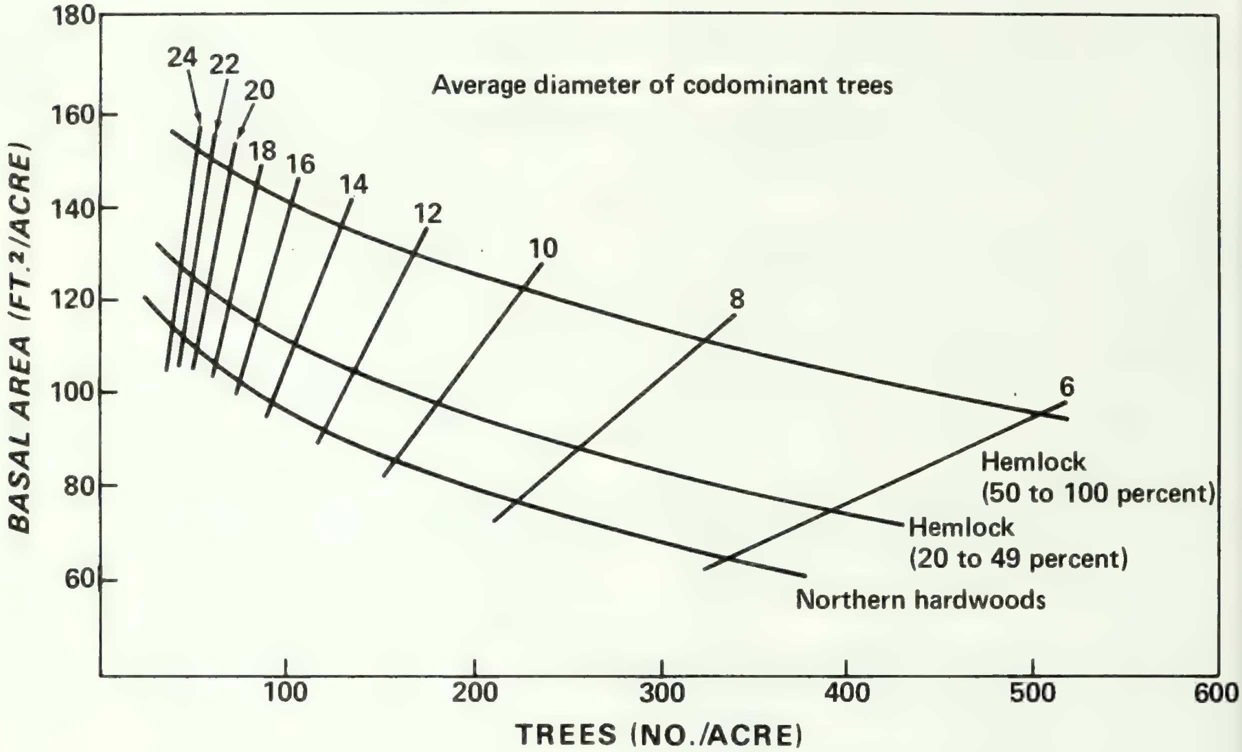

Figure 8.—*Stocking levels for even-age hemlock-hardwood stands in the Lake States by basal area and numbers of trees for specified diameter classes and certain percentages of hemlock and hardwoods.*

Table 2.—*Defects and cull percents caused by them*

Defect	Position within merchantable length of tree	Condition or degree	Class	Cull percent[1] 1-log tree	2-log tree	2½-log tree	3-log tree	4-log tree
Broken or dead limb								
(At least 6 inches in diameter)	Anywhere	Large	3	20	17	14	13	11
(Less than 6 inches in diameter)	Anywhere	Small	1	5	4	4	3	3
Broken or dead top (Broken or rotten close enough to top limit of merchantability to indicate loss in scale.)	---	---	3	20	17	14	13	11
Butt rot (At least 1/3 of log lost. If not visible, detectable by blow.)	First log	Advanced	5	39	35	28	25	22
Canker	First log	Advanced	6	56	50	41	36	32
	Above first log	Advanced	4	26	24	20	17	15
Hidden rot (Cannot be detected in standing tree.)	Anywhere	---	2	9	8	6	6	5
Conk	First log	Active	5	39	35	28	25	22
	Above first log	Active	4	26	24	20	17	15
	Anywhere	Sterile	1	5	4	4	3	3
Crack								
(Open. At least 1/3 of log lost.)	First log	Large	5	39	35	28	25	22
(Open. At least 1/3 of log lost.)	Above first log	Large	3	20	17	14	13	11
(Open. Less than 1/3 of log lost.)	Anywhere	Small	2	9	8	6	6	5
Crook or sweep								
(More than 2/3 volume lost.)	First log	Excessive	5	39	35	28	25	22
(1/3 to and including 2/3 volume lost.)	First log	Moderate	4	26	24	20	17	15
(Less than 1/3 volume lost.)	First log	Slight	2	9	8	6	6	5
(More than 2/3 volume lost.)	Intermediate log	Excessive	4	26	24	20	17	15
(To and including 2/3 volume lost.)	Intermediate log	Slight to moderate	2	9	8	6	6	5
(More than 2/3 volume lost.)	Top log	Excessive	3	20	17	14	13	11
(To and including 2/3 volume lost.)	Top log	Slight to moderate	2	9	8	6	6	5
Hole								
(Cavity. At least 1/3 of log lost.)	First log	Large	5	39	35	28	28	22
(Cavity. At least 1/3 of log lost.)	Above first log	Large	4	26	24	20	17	15
(Cavity. Less than 1/3 of log lost.)	Anywhere	Small	2	9	8	6	6	5
Ingrown bark								
(Bark folded into right cylinder.)	First log	---	1	5	4	4	3	3
Rotten burl								
(At least 1/4 of log affected.)	Anywhere	Large	4	26	24	20	17	15
(Less than 1/4 of log affected.)	Anywhere	Small	1	5	4	4	3	3
Scar								
(At least 1/4 of log affected.)	Anywhere	Large	4	26	24	20	17	15
(Less than 1/4 of log affected.)	Anywhere	Small	2	9	8	6	6	5
Seam (Open or tight.)	Anywhere	Spiral	6	56	50	41	36	32
(Tight. At least 6 feet long.)	Anywhere	Large, straight	3	20	17	14	13	11
(Tight. Less than 6 feet long.)	Anywhere	Small, straight	2	9	8	6	6	5

[1]Class averages.

How to Mark Individual Northern Hardwood Trees

After decisions are made concerning residual stocking and structure (table 1), the next step focuses attention on individual trees. Much of the decision to cut or leave is based on the potential of a tree to supply high quality saw logs or veneer. Part depends on the rate at which the tree grows and part depends on its influence on surrounding trees.

The following factors should be weighed in deciding which trees to cut or leave. To upgrade stand quality, minimize loss from cull and mortality, and enhance the potential for the future production, consider these items in the order given:

1. Risk: remove any tree that, in your judgment, will not live and grow until the next cut.

2. Cull: remove cull and highly defective trees that will not increase in value during the cutting cycle. (See Appendix, table 2, for a detailed summary.)

3. Form, crown, and branching habits: remove crooked or leaning trees, those with an acute angle between limbs and bole, and those with short clear length or large limb diameter.

4. Species: low-quality timber has about the same value regardless of species, and high-quality logs of any of the major species are usually salable. Nevertheless, determine local preferences for species.

5. Crown position: in addition to the above items consider the position of a tree in relation to the other trees to be left in a stand. Mark for removal trees that are interfering with the full development of other trees of higher potential quality, thus providing the better trees freedom for crown development in all directions.

6. Size: finally, consider tree diameter. Generally, most tree species within the northern hardwood type become economically mature when they reach 20 to 24 inches d.b.h. Trees that have reached, or grown beyond, economic maturity do not pay their way in comparison to smaller trees.

More detailed information is provided in the following sections to aid in the decision of what constitutes serious cull, trees of good quality potential, and how to judge the importance of crown position.

This information is based both on formal study and long-term observation and should be used as a flexible guide to be modified according to local conditions.

How to Decide What Trees to Leave

Especially in all-age forestry, trees are of mixed sizes and of varying degrees of importance to their surrounding stand. Decisions regarding the trees to leave should be guided by the following tree classification and modified by the crown classification after that.

Tree Categories

Tree class 1: good growing stock.—The tree must be straight, dominant or codominant, free from crook or lean, and with less than 10 percent cull (class 1 or better). An average of at least 50 percent of the total height of the tree must be clear length. (Consider each tree to have four faces on its main stem. Each face will include one-quarter of the circumference of the tree. The average of the clear length on these four faces will be the average clear length of the tree.) In trees 9 inches or less in diameter at breast height, limbs and knots under 1 inch in diameter may be permitted in clear length. The crown should be full and the vigor good.

Tree class 2: satisfactory growing stock.—Trees of intermediate crown class or better are permitted in this class. The trees may have no defect or crook or internal decay involving over 20 percent cull (class 2). Trees must not have acute forks or multiple crowns; however, U-shaped forks are permitted above 35 feet. An average of at least one-third of the total height must be in clear length. In trees 9 inches or less in diameter at breast height, limbs and knots under 1 inch diameter are permitted in clear length.

Tree class 3: poor growing stock.—Trees that otherwise meet the specifications for tree class 2 but are competing with class 1 trees for growing

ice and trees merchantable for saw logs or potenlly merchantable that do not meet the specificans for the first two classes are included in this ss.

ree class 4: nongrowing stock.—Cull trees and es with no potential merchantability other than chemical wood or pulpwood are included in this ss.

own Categories

ominant crown class.—These trees are the largest; ir crowns and merchantable height are set and tural practices no longer will have a measurable ect on tree characteristics. The major value of se trees is their approach to final yield and luence on the surrounding stand. Silviculturally, se trees are mature and should be removed when y no longer have a beneficial effect on the surnding trees, i.e., when their influence on clear gth of neighboring trees is minimal or when they noticeably suppressing understory and neighring codominants. Trees in the dominant size ss, even though they may rate as cull class 2 or rse, may be left if they have a beneficial effect on her regeneration or neighboring trees.

odominant.—In saw log stands these will often be all saw logs (14 to 19 inches d.b.h.). Select trees leave on the basis of: (1) potential for increasing ade and merchantable height; (2) least cull (cull ss 2 or better); and (3) beneficial influence on the intermediates and other codominants. These trees should provide side shade for well formed intermediate.

Weak codominants.—In saw log stands the weak codominants are the 10- to 14-inch class. These crown classes continue to have an important effect on lesser classes but the most important job is to select those which will make the most rapid increase in value. The least desirable trees in this class have permanent merchantable height stoppers such as low forks with large diameter fork members, other serious cull and low grade improvement potential. Correctable forks have a partly or wholly suppressed fork member less than one-third of the tree diameter at the point of the fork. The best trees should be potential grade 2 or better, have crowns of at least medium density and crown widths average for the d.b.h. class.

In the pole class (5 to 9 inches), a combination of side shade and within-crown competition, controls lower branch mortality and subsequent merchantable length. Trees left in this class should have good form, be free of serious defect and have a good crown of average width and medium or better density. Too heavy a release of trees in this class with crowns of less than average width and density will result in losses of merchantability and quality. Especially in previously unmanaged stands, many poles will have good stem form and clean boles coupled with small crowns. The object of release should be to develop denser crowns without reducing clear length.

Table 3.—*Crown area by diameter classes and theoretical stocking for shelterwood cover (Godman and Tubbs 1973)*

D.b.h.	60 Percent crown cover											
	Northern hardwoods				Basswood				Hemlock-conifers			
	Trees	Basal area	Spacing	Crown area per tree	Trees	Basal area	Spacing	Crown area per tree	Trees	Basal area	Spacing	Crown area per tree
Inches	*Numbers*	*Square feet*	*Feet*	*Square feet*	*Numbers*	*Square feet*	*Feet*	*Square feet*	*Numbers*	*Square feet*	*Feet*	*Square feet*
10	94	51	22	279	171	93	16	153	224	133	13	107
11	80	53	23	325	144	95	17	181	203	133	15	129
12	70	55	25	373	126	99	19	207	170	133	16	154
13	62	57	26	422	108	100	20	241	144	133	17	181
14	54	58	28	480	95	102	21	274	125	133	19	209
15	49	60	30	536	84	103	23	312	108	133	20	241
16	44	61	32	598	75	105	24	349	95	133	21	274
17	40	62	33	662	67	106	25	388	85	133	23	309
18	36	63	35	728	61	108	27	427	76	133	24	346
19	32	64	37	803	56	110	28	470	68	133	25	386
20	20	65	38	881	50	110	29	518	61	133	27	427
21	27	66	40	952	46	111	31	567	56	133	28	471
22	25	67	42	1,035	43	112	32	614	50	133	29	518
23	23	67	43	1,120	39	113	33	665	46	133	31	563
24	22	68	45	1,207	37	115	35	712	43	133	32	612

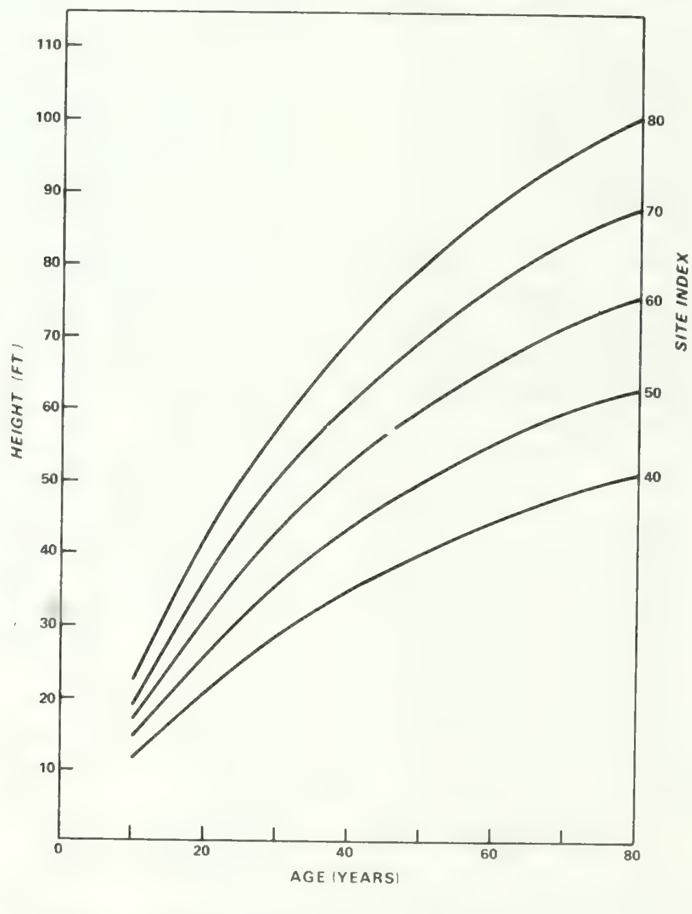

Figure 9.—*Site index graph for paper birch in northern Wisconsin.*

Metric Conversion Factors

convert	to	Multiply by
res	Hectares	0.405
ard feet[1]	Cubic meters	0.005
ard feet/acre[1]	Cubic meters/hectare	0.012
ains	Meters	20.117
rds[1]	Cubic meters	2.605
rds/acre[1]	Cubic meters/hectare	6.437
bic feet	Cubic meters	0.028
bic feet/acre	Cubic meters/hectare	0.070
grees Fahrenheit	Degrees Celsius	[2]
et	Meters	0.305
llons	Liters	3.785
llons/acre	Liters/hectare	9.353
ches	Centimeters	2.540
les	Kilometers	1.609
les/hour	Meters/second	0.447
mber/acre	Number/hectare	2.471
nces	Grams	28.350
nces/acre	Grams/hectare	70.053
unds	Kilograms	0.454
unds/acre	Kilograms/hectare	1.121
unds/gallon	Kilograms/liter	0.120
uare feet	Square meters	0.093
uare feet/acre	Square meters/hectare	0.230
ns	Metric tons	0.907
ns/acre	Metric tons/hectare	2.242

[1]The conversion of board feet and cords to cubic ters can only be approximate; the factors are based an assumed 5.663 board feet (log scale) per cubic ot and a cord with 92 cubic feet of solid material.

[2]To convert °F to °C, use the formula 5/9 (°F-32) $\frac{°F-32}{1.8}$.

Common and Scientific Names of Plants and Animals

Plants

Ash, black. . . . .*Fraxinus nigra*
Aspen . . . .*Populus* spp.
Balsam. . . . .*Abies* spp.
Basswood. . . . .*Tilia* spp.
Beech . . . .*Fagus* spp.
Birch, paper. . . . .*Betula papyrifera*
yellow . . . .*Betula alleghaniensis*
Elm . . . .*Ulmus* spp.
Hemlock . . . .*Tsuga* spp.
Maple, red. . . . .*Acer rubrum*
sugar. . . . .*Acer saccharum*
Oak, northern red . . . . .*Quercus rubra*
Spruce. . . . .*Picea* spp.
White-cedar, northern . . .*Thuja occidentalis*

Animals

Deer, white-tailed. . . . .*Dama virginiana*
Hare, snowshoe. . . . . . .*Lepus americanus*

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key – out of the reach of children and animals – and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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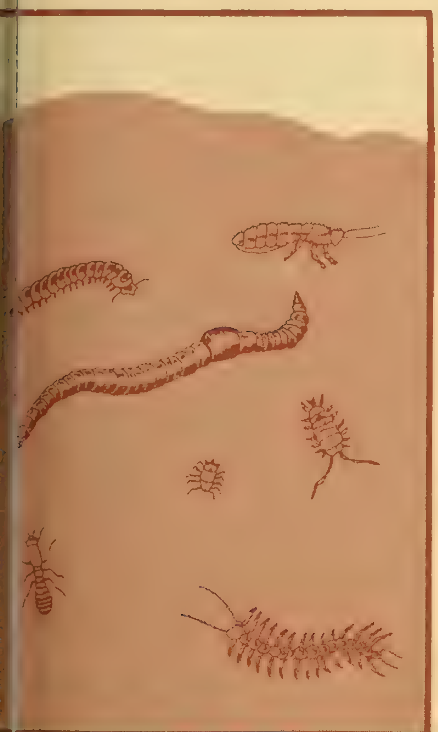

Survey of SOIL INVERTEBRATES two Aspen Forests northern Minnesota.

Wagner, W. J. Mattson, and J. A. Witter

TH CENTRAL FOREST EXPERIMENT STATION

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A SURVEY OF SOIL INVERTEBRATES IN 'WO ASPEN FORESTS IN NORTHERN MINNESOTA

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Ioductivity of ecosystems depends to a large nt on the quantity of available nutrients. In ral ecosystems, much of the nutrient stock is vailable because it is bound in live and dead nic matter. Additions to the pool of available ients come from several sources, but the largest most important one is dead organic matter. refore, the productivity of ecosystems is often to be related to the rate of nutrient release n, or the mineralization of, organic litter larov 1971, Satchell 1974).

n abundant and diverse complex of soil fauna microflora live on the dead organic matter in estrial ecosystems. These fauna and flora tract in manifold ways to facilitate and enhance rate of mineralization of organic debris and the elopment of soil structure. The consensus is that fauna, by themselves, cannot mineralize litter use most animals lack the enzymes systems ssary to break down the majority of compounds itter. Mineralization, then, is accomplished narily by the soil microflora interacting with animals. Other contributions by soil fauna have reviewed by Crossley (1977) and Satchell 4).

il fauna are often classified according to their y sizes: microfauna (size<0.2 mm), mesofauna mm <size<10 mm), and macrofauna (size>10) (Wallwork 1970). The microfauna are mainly ozoans; whereas the mesofauna include a tremendous variety of animals: nematodes, a plethora of arthropods, small molluscs, and Enchytraeidae worms. The macrofauna contain the larger elements of the arthropods, molluscs, enchytraeids, lumbricid worms, and the soil dwelling vertebrates.

The abundance and composition of soil litter fauna vary in relation to many factors; some of which are the physical environment, the parent mineral substrates, the vegetation, and other organisms. For example, Satchell (1974) cited a report which speculated that faunal biomass is temperature-limited in boreal and higher latitudes, moisture-limited in arid zones, and food-limited in tropical zones because of competition from microbes. In other zones, it may be limited by combinations of temperature, base-poor soils, oxygen tension, acidity, and food supply.

Patterns of species compositions for a wide variety of ecosystems are now recognizable. For example, in acidic soil-litter substrates (mor soils) where the dominant vegetation is often coniferous or ericaceous, the most abundant soil animals are mites, Collembola, enchytraeid worms, and such insects as beetles. At the other end of the spectrum where the soil-litter substrate is neutral to slightly alkaline (mull soils) and the dominant vegetation is deciduous angiosperms, the most significant soil animals are lumbricid worms, myriopods, isopods, large groups of beetles and flies, and lastly mites and Collembola

(Wallwork 1970). In soil-litter substrates that are intermediate between the classic mor and mull types, the soil animals have intermediate compositions.

Trembling aspen, *Populus tremuloides,* is a predominant tree in the vegetation of the Great Lakes Region — usually forming nearly pure stands or occurring as occasional, residual individuals in forests dominated by other species. About one-third of the commercial forests in the Lake States are dominated by aspen trees. Aspen occurs on a wide variety of soil types, from sandy outwash plains to moist loams (Graham *et al.* 1963). The best aspen forests seem to occur where the soil texture is fine (high silts and clay contents) and the water tables are within a few feet of the surface (Fralish 1972). The understory vegetation usually consists of a rich variety of deciduous shrubs and herbs, as well as seedlings and saplings of various deciduous and coniferous tree species (Ohmann and Ream 1971).

Aspen leaf litter and that of its associated shrubs and herbs tend to have a medium-high calcium content compared with coniferous litter (Henry 1973). This should promote the development of neutral soils, and more mull-like rather than mor-like populations of soil invertebrates and micro-organisms. The rate of decomposition of aspen foliage is somewhat intermediate between fast species such as alders, elms, and ashes, and slow species such as beech, most oaks, and conifers (Wallwork 1970, Cummins 1974).

Some of the factors which influence the rate at which leaves naturally decompose are its C/N ratio, polyphenolic content, calcium concentration, and the ambient temperature and moisture conditions. For example, high C/N ratios and polyphenolic contents, and low temperatures and moisture conditions all retard decomposition rates.

Although aspen ecosystems are prominent in the Great Lakes Region and parts of Canada and Alaska, knowledge about organisms and processes operating in the soil-litter milieu of such ecosystems is just beginning to accumulate (Carter and Cragg 1976, Mitchell and Parkinson 1976, Visser and Parkinson 1975). The purpose of the present exploratory study was to (1) identify the major soil-litter invertebrates found in two aspen forests in northern Minnesota, and (2) to measure their population densities whenever possible, thereby provi[illegible] baseline knowledge for future investigations.

MATERIALS AND METHOD[illegible]

We intensively sampled two aspen stands (h[illegible] after referred to as Black River and Pine Stum[illegible] Koochiching County, Minnesota, during [illegible] summer of 1972. Both plots had been previo[illegible] selected for studies of forest tent caterpillar-as[illegible] ecosystem interactions. Plot size was arbitraril[illegible] at 10 hectares and each was subdivided into 4 q[illegible] rats of equal size. All samples were taken from [illegible] randomly located subplots (20 by 20 m) within [illegible] quadrat.

Vegetation in the plots was analyzed, soils w[illegible] classified[1], and we measured: (1) soil horizon de[illegible] on nearly 180 soil cores from each plot and (2)[illegible] pH from the mid-point of the soil horizons (02, [illegible] and B) of the soil cores using a Hellige-Truog [illegible] reaction test kit.

To recover soil invertebrates from the soil-li[illegible] milieu, we employed three standard technique[illegible] dry funnel extraction, (2) hand sorting of si[illegible] soil, and (3) pitfall traps. The first techniqu[illegible] usually employed for recovering small mesof[illegible] whereas the second and third techniques [illegible] employed for recovering large mesofauna [illegible] macrofauna. General reviews of these methods [illegible] be found in Macfadyen (1962) and Edwards [illegible] Fletcher (1971).

Dry Funnel Method

Description of apparatus

Two funnel extracting units of the Tullgren [illegible] were designed to accommodate 30 soil core sam[illegible] each. Black plastic drain pipe sections (3.80 c[illegible] diameter by 17.85 cm long) were used to hol[illegible] soil core samples. Sixteen mesh/in² hardware [illegible] was glued to one end of each pipe section to hol[illegible]

[1]*Paul Nyberg, USDA Soil Conservation Ser[illegible] Grand Rapids, Minnesota.*

l core in place. The circumference of the mesh een was larger than the tube to which it was ached and slightly smaller than the maximum meter of the funnel on which it rested. The een kept the holding tube away from the funnel l allowed for the dissipation of free, moist air as h core sample dried. This prevented moisture m building up on the inside wall of the funnel l ultimately increased the yields of the unit. tached to the bottom of each funnel was a 22 ml l which contained 95 percent ethyl alcohol as a ing and preserving agent.

A heat and light source above the soil cores was pplied by 9-watt, 120-volt, outdoor Christmas e incandescent light bulbs. Individual bulbs were centrally into the closed end of beverage cans. e cans were positioned over the top of the plastic lding tubes so that each bulb was approximately 5 cm from the top of a soil core sample. mperatures were maintained at ca. 40 C at the of the soil during the 120-hour extracting period.

The soil core sampler was designed to extract a l core 3.15 cm in diameter by 47.3 cm long. One e of the chrome plated tubing of the sampler was en, giving an undisturbed picture of the soil ofile. This open face provided the means for re- oving the soil core intact from the sampler.

mpling methods

Five randomly picked 20- by 20-m subplots in ch quadrat supplied all soil core samples. These bplots were further divided into 100 2- by 2-m² o-subplots. Three such plots were chosen randomly, thout replacement, from within each subplot. e soil core sample was taken from each sub- bplot during each of three sampling periods. This elded 60 core samples for each stand on each mpling date. The sampling dates for the Pine ump stand were June 12, July 11, and August 6. e sampling dates for the Black River stand were ne 19, July 17, and August 12. Core samples re immediately placed intact into the plastic bes with the litter end resting on the screen. The en end of the tube was sealed with a cork and the reen end was covered with tin foil.

Hand-Sorting Method

From each of the 20 subplots, we collected 1 square block of soil (30.4 by 30.4 by 15.3 cm) in mid-June, July, and August, to recover the larger mesofauna and macrofauna. The sample points within subplots were picked randomly as were the soil core samples. The soil blocks were passed through three sieves having mesh sizes of 4, 16, and 64 per square inch. All fauna were preserved in 95 percent ethanol.

Pitfall Method

Ten pitfall traps were placed near the center of each study stand in a linear series 20 m apart. Each trap (a can, 10.2 cm wide and 12.0 cm deep, a screen retrieving plunger, and a rainshield hood) was buried in the ground, and partially filled with antifreeze. Traps were emptied every 13 days. Collection dates were July 16, 29, and August 11 at Pine Stump; and July 17, 30, and August 12 at Black River.

STUDY PLOT DESCRIPTIONS

Both study plots were dominated by trembling aspen, *P. tremuloides,* trees that were between 35 to 40 years old. Total tree basal area/acre was about 97 feet² (22.3 m²/ha) at Pine Stump and 116 feet² (26.7 m²/ha) at Black River. Other less abundant tree associates were balsam poplar *P. balsamifera,* paper birch, *Betula papyifera,* black ash, *Fraxinus nigra,* and balsam fir, *Abies balsamea* (table 2, Appendix).

Common shrubs in both plots were beaked hazel, *Corylus cornuta,* red-osier dogwood, *Cornus stolonifera,* chokecherry, *Prunus virginiana,* and arrowwood, *Viburnum rafinesquianum.* However, Black River shrubs were predominantly hazel, dogwood, alder-leafed buckthorn, *Rhamnus alnifolia,* and tag alder, *Alnus rugosa.* Pine Stump shrubs were predominantly hazel, arrowwood, and chokecherry. Shrub densities averaged about 10,000/acre (24,000/ha) at Black River and about 6,600/acre (16,302/ha) at Pine Stump.

Herbaceous vegetation was grossly similar in both study plots. Species having frequencies of occurrence (FO) of ⩾50 percent at both areas were the following: dwarf raspberry, *Rubus pubescens,* false lily of the valley, *Mianthemum canadense,* bunchberry, *Cornus canadensis,* and wild sarsaparilla, *Aralia*

nudicaulis. Pine Stump, in addition, had an abundance (FO = 92 percent) of large leaf aster, *Aster macrophyllus*, which was uncommon at Black River (FO ≤10 percent). Herbaceous standing crops averaged 35 g/m² dry weight and 75 g/m² dry weight in midsummer at Black River and Pine Stump, respectively.

Surface soils (A,B horizons) in both plots were clay loams, silt loams, silty-clay loams, and fine sandy loams. The substratum or C horizons were usually clay, clay loams, silty and clayey loams or loam glacial tills. Drainage was moderate to poor in most of the soils examined because of the heavy subsoils and substrata.

The undecomposed litter layer (01) was about 1.4 cm deep at Black River and 3.4 cm at Pine Stump (table 1, Appendix). The partially decomposed litter layer (02) and the mineral surface soils (A) were between 6 to 8 cm and 11 to 14 cm deep, respectively, at both areas. Although the 01 layer was deeper at Pine Stump, the 02 and A horizons were consistently wider at Black River (8.5 vs. 6.4 and 14.3 vs. 10.9 cm).

All soil horizons tended to be slightly acidic (5.7 to 6.6) except at Black River where the B horizon was neutral (7.25). Generally pH values increased from the surface to the lower soil horizons. Furthermore, the Black River soils had significantly higher pH values than the Pine Stump soils.

RESULTS AND DISCUSSION

All of our samples (core, block, and pitfall) yielded 4 phyla, 7 classes, 23 orders, and 134 families of invertebrates (see List of Invertebrates, Appendix). Listed in order of decreasing taxonomic diversity, the four phyla were: Arthropoda, Mollusca, Annelida, and Nematoda. Arthropoda contained 5 of the 7 classes, 19 of the 23 orders, and 125 of the 134 families. Insecta was the single largest class containing 11 orders and 84 families. This is a minimal estimate of the taxonomic variety of soil fauna because we could not identify all of the organisms. For example, only a 3 percent subsample of the total mite collection was identified by specialists and none of the spiders nor Nematodes have yet been identified. In fact, none of our sampling methods was valid for Nematodes so they are grossly unde[r]represented in this study.

The ensuing reports will discuss the biology an[d] ecology of the major groups of soil invertebrates. Th[e] sequence in which they are covered reflects onl[y] their alphabetical order displayed in table 3.

Oligochaeta: Opisthopora

Annelids are probably the best known of all so[il] animals. The dominant families in the temperat[e] zones are Enchytraeidae (potworms) and Lumbricida[e] (earthworms). Enchytraeids are small (most specie[s] <1 cm) pale worms that thrive in acidic, organi[c] soils. Lumbricids, on the other hand, are many-fol[d] larger than enchytraeids and reach their greates[t] densities in neutral to slightly alkaline soils. Ligh[t] and medium loams usually have greater number[s] and species of earthworms than do clays and alluvia[l] soils (Lofty 1974).

Earthworms are entirely saprophagous. They fee[d] on many kinds of plant litter but prefer plant debri[s] with high nitrogen and sugar levels and low poly[-] phenol levels — just like most other saprophages[.] Oligochaetes have an important effect on litte[r] breakdown and soil structure through such activitie[s] as: (1) fragmenting plant debris into smalle[r] particles, (2) incorporating fragmented and decom[-] posed plant debris into lower soil horizons, (3[)] dumping feces (cast material) onto soil surface an[d] litter layers, (4) enhancing activity of micro[-] organisms and (5) facilitating the formation o[f] stable organo-mineral complexes in the soil.

Two species of earthworms were dominant in th[e] study stands: *Dendrobaena octaedra* a small, non[-] burrowing, acid-tolerant species which showed [a] preference for the upper organic layers; an[d] *Allolobophora trapezoides* a larger, burrowin[g] species which was often found deep within the soil[.] Two incidental species were also recovered: *Dendro[-] baena rubida* and *Octolasion tyrtaeum*.

The density of *Dendroboena* spp. was twice a[s] great (124 vs. 60 m²) at Pine Stump stand as a[t] Black River. On the other hand, the density of th[e] burrowing earthworm, *A. trapezoides,* wa[s] determined to be 0 at Pine Stump and 9/m² at Blac[k] River. These densities were comparable to thos[e] reported by Wallwork (1970) for earthworms i[n]

woodland mull-soils (73 to 493/m²). We have no explanation for the scarcity of *A. trapezoides* at Pine Stump except that soil conditions may have been too acidic for it. Differences in densities of *Dendrobaena* between stands may be related to the presence of twice as much surface litter and the lack of *A. trapezoides* at Pine Stump. *A trapezoides* may create unfavorable conditions for *Dendrobaena* by rapidly consuming their food (litter) and thereby destroying their micro-environment, 01, 02 (organic) layers.

A. trapezoides probably has more effect on soil structure than *Dendrobaena* spp. because of its burrowing habits. For example, the soils at Black River were typically well granulated and the A1 horizons were very dark, especially in quadrats 1 and 2 which had greatest densities of *A. trapezoides*. This dark coloration is due to the incorporation of organic matter from the litter layer into the subsurface soil — probably due to the activities of *A. trapezoides*. These worms may have been responsible for the shallow litter layer at Black River which was only half of that at Pine Stump.

Arachnida: Acari

Mites constitute one of the largest, most diverse and perhaps most abundant group of soil-inhabiting arthropods. For example, there are 4 major suborders: Acaridei (= Astigmata), Prostigmata, Mesostigmata, and Oribatei (= Cryptostigmata) together having several hundred families of soil-inhabiting mites (Wallwork 1970). Among these families, one can find a broad range of feeding habits: detritus, fungal, bacterial, and protozoan feeders as well as insect and mite predators and parasites. In forest soils the majority of detritus and micro-organism feeders belong to the Oribatei (Ghilarov 1971, Butcher and Snider 1971).

Densities of mites range from about 60,000 to over 200,000/m² in forest soils (Ghilarov 1971, Wallwork 1970, Harding and Stuttard 1974). Because of their microscopic size, they contribute less to mixing of soil layers than do earthworms. Their main contributions to litter decomposition are through the comminution of organic material and interactions with soil-microorganisms, especially fungi (Mitchell and Parkinson 1976).

In this study we found all of the 4 major suborders, 36 families and 53 species from 6 Tullgren core samples randomly selected from each stand. Recall that 180 Tullgren samples were collected from each stand. The partial list of species (table 3, Appendix) probably represents as little as 25 percent of the total numbers of species present.[2] If our small sample is indeed representative, then the most common species were *Oppiella nova* (Oppidae), *Synchthonius crenulatus* (Brachychthoniidae), *Tectocepheus velatus* (Tectocepheidae), *Suctobelba* spp. (Suctobelbidae), *Cocceupodes* spp. (Eupodidae), and *Rhagidia* spp. (Rhagidiiae). The first four genera belong to the Oribatei and the last two genera to the Prostigmata. Almost half of all species (26/53) belonged to the Oribatei.

Average population densities (based on June, July, and August samples) were about 87,000 and 94,000/m² at Black River and Pine Stump, respectively (fig. 1, Appendix). Densities were lowest in the June samples and highest in most cases in August, presumably due to either vertical population movements or rapid reproduction during the summer. Between June and August populations approximately doubled from about 50,000/m² to 100,000/m². Seasonal variations in mite densities are well known, but most evidence indicates that peaks occur during fall and winter months, and troughs occur during summer months (Wallwork 1970). If this is true, then the mite densities observed in our study plots may represent only the lower extreme of the annual spectrum of densities.

Variations in population densities also occurred among different quadrats (fig. 1, Appendix). Such variations were not related to the depth and/or pH of the 01 and 02 (organic matter) layers. Probably they reflected variations in litter moisture contents, or some other unmeasured variable, or were simply a result of the sampling techniques.

Arachnida: Araneida

Spiders are perhaps the best known of all arachnids. They occur in a wide variety of habitats and many families have a close association with the soil-litter environment. They are strictly predators. The impact of their predation on the soil-dwelling invertebrates is poorly known.

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[2]*Personal communication with Mr. Roy A. Norton, 1973.*

The Pine Stump stand had more than twice as many spiders (24.9 vs. 9.6/m²) as the Black River stand, according to soil sieve samples (table 4, Appendix). Although there was variation among quadrats the data indicate that population densities tended to decline from June to August. For example, overall mean densities in August were only 60 to 80 percent of those recorded in June.

Pitfall traps, which caught the larger spiders, revealed that Black River may have been slightly more productive or may have had more active species (117 vs. 82) than Pine Stump. These data represent only a 1-month period, mid-July to mid-August.

Arachnida: Chelonethida

Pseudoscorpions are often found in moist, soil-litter environments, but usually are not very abundant (Wallwork 1970). Pseudoscorpions, like spiders, are strictly zoophagous, feeding on such animals as Collembola, other small insects, mites, myriapods, and enchytraeid worms. Three species *Microbisium brunneum, M. confusum,* and *Mundochtonius rossi)* were found. *M. brunneum,* a species with a wide range of geographic distribution in eastern Canada and the northern United States, is typically associated with acidic environments, such as tamarack, *Larix laricina,* bogs (Hoff 1949). It was recovered from only the Pine Stump stand. *M. confusum,* another widely distributed species with a range extending farther to the south than *M. brunneum,* was recorded from both stands. It is commonly found in forest litter or soil, and in decaying logs or stumps (Hoff 1949). Although it sometimes occurs with *M. brunneum* on wet sites in northern Illinois, it apparently prefers drier uplands.[3] It can be separated from the latter by its smaller body and palp size (Hoff 1949).

M. rossi, also a common northern pseudoscorpion, was present in both stands. It prefers the same type of habitat as *M. confusum.*

Densities of pseudoscorpions were 2- to 4-fold greater (e.g., 100 vs. 450/m²) at Pine Stump than at Black River (fig. 2). Such differences may reflect difference in the abundance of prey between the two stands. In both stands, highest population densities occurred in July and lowest densities occurred in June. About 60 to 85 percent of the individuals were immatures at both Pine Stump and Black River.

Arachnida: Phalangida

Harvestmen are common in the surface litter layer of many forests. They are primarily zoophagous, feeding on a wide variety of insects, such as fly and beetle larvae, and other invertebrates. They are highly prone to desiccation and require a continuous source of free drinking water. Therefore, most species are found in areas with high humidity and peak activity often occurs in the evening (Wallwork 1970).

We recovered six species of harvestmen: *Leiobunum calcar, L. politum, L. ventricosum, Sabacon crassipalpe, Crosbycus dasycnemus,* and *Odiellus pictus pictus,* from pitfall traps. We captured more than twice (138 vs. 57) as many harvestmen at Pine Stump than we did at Black River.

The most abundant species at Pine Stump and Black River were *L. calcar, L. politum,* and *O. pictus pictus. S. crassipalpe* was recovered only at Black River, and *C. dasychemus* was recovered only at Pine Stump.

Chilopoda: Geophilomorpha and Lithobiomorpha

Most centipedes are very susceptible to desiccation and, therefore, are usually confined to moist, but not wet, micro-environments. For example, the Geophilomorpha, which are essentially subterranean, were usually found below the litter surface in the 02 and A2 soil horizons, in small groups of 2 to 5. On the other hand, the Lithobiomorpha are heavy-bodied forms which cannot burrow like the slender Geophilomorpha and so are usually found in existing soil pore space — under surface litter, beneath fresh plant debris, under logs, and stones.

The chilopods are predaceous and feed on a wide variety of insects, mites, spiders, nematodes, and molluscs (Wallwork 1970).

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[3] *Personal communication with Dr. William Muchmore, 1973.*

Centipede densities were 6.3/m² at Black River and 5.2/m² at Pine Stump. Two-thirds at Black River and 2/5 at Pine Stump were lithobiomorphs. All others were geophilomorphs.

Diplopoda: Polydesmida and Iuliformia

Millipedes, like centipedes, do not possess a very efficient waterproofing layer on their cuticles and, therefore, most are susceptible to desiccation. Millipedes typically live in the soil-organic layers among leaves, rotting wood, and under stones. Some can burrow into the lower litter and upper mineral layers. Unlike centipedes, however, millipedes are phytophagous and saprophagous (Edwards 1974). They are known to consume large quantities of leaves and appear to show a preference for plant species having high calcium concentrations. Their feeding promotes litter breakdown through comminution of plant debris (McBrayer 1973).

Our samples revealed 2 orders of millipedes: the round-backed form, Iuliforma, and the flat-backed form, Polydesmida. The former are burrowers, whereas the latter are not.

Black River had roughly 5-fold more (4.5 vs. 0.9/m²) millipedes than did Pine Stump, based on soil sieve samples. Two-thirds were polydesmids at Black River, whereas only one individual from all samples at Pine Stump belonged to this order. All other specimens found were the burrowing iuliforms. These data suggest that the litter layer at Pine Stump may have been too dry for the Polydesmids. Moreover, at Black River, most polydesmids (68 percent) came from quadrat 1 which was wetter than all other quadrats. Another reason for the differences in abundance of polydesmids between stands could be differences in soil pH. Diplopods are usually more abundant in calcareous rather than in base deficient soils such as occurred at Pine Stump (Wallwork 1970).

Insecta: Coleoptera

Beetles are often the most abundant and varied group of soil-inhabiting macro-arthropods (Wallwork 1970). The six most common families of beetles found in the soil-litter milieu are usually Carabidae (zoophagous), Staphylindidae (zoophagous and saprophagous), Elateridae (zoophagous and saprophagous), Scarabaeidae (phytophagous and saprophagous), Silphidae (saprophagous), and Pselaphidae (zoophagous). Most beetles occupy the uppermost part of the litter environment where their major ecological roles are the comminution of organic debris and predation.

Our samples revealed 22 different families of beetles in the soil-litter environment (table 3, Appendix). The numerically dominant taxa were clearly Staphylinidae (rove beetles), Carabidae (ground beetles), Elateridae (click beetles), and Cantharidae (soldier beetles) (table 5, Appendix). Interestingly, these families are comprised primarily of predaceous forms except for Elateridae which also has many saprophagous forms.

Densities of beetle larvae (all species) were slightly higher at Black River than at Pine Stump (432 vs. 328/m²), based on the funnel method (table 6, Appendix), just as were densities of beetle adults (19 vs. 16/m²). The funnel method suggested that beetle densities tend to increase from June to August. On the other hand, the soil sieve method, which recovers larger larval forms, did not corroborate this pattern: beetle densities increased at Black River and decreased over time at Pine Stump.

Insecta: Collembola

Collembola or springtails are usually the most abundant insect order occurring in soil-litter environments. Population densities vary with ecosystems but are known to range from 5,000/m² to 200,000/m² (Wallwork 1970, Harding and Stuttard 1974). In many respects, springtails are ecologically similar to mites — particularly to the predominantly saprophagous Oribatei. For example, both groups have similar physical environmental requirements, and both occupy primarily the upper organic layers, especially the zone of active decomposition (Wallwork 1970). Neither mites nor springtails can burrow and so use the existing soil spaces. Their diets are probably very similar also, consuming fungal hyphae, spores, bacteria, pollen, algae, feces, and plant debris. Many springtails can be classified as opportunists because they are not specialized consumers.

Thirty-seven species (belonging to nine families) of springtails were identified from a randomly

selected subset (60/180) of samples (table 7, Appendix). The subsample represented a cross-section of samples from every quadrat on each of the three sample dates. Sixty percent of the individuals at Black River and 71 percent at Pine Stump were positively identified to species level. The remaining specimens could not be identified because they were immatures. It should be noted that the Tullgren samples are biased in favor of the edaphic forms. Surface and litter dwelling forms may be inaccurately represented.

Folsomia candida (Isotomidae) was the most abundant springtail found at both areas (table 8). It is a white, eyeless, soil form. Other very common species were: *Tullbergia eollis, Arrhopalites benitus,* and *Isotoma olivacea.* These 4 species comprised 61 percent of the total numbers of specimens at both areas. Two other species *(Guthriella vetusta* and *Tomocerus vulgaris)* were very numerous (each comprising 5 to 10 percent of total population) at Black River, but were scarce (<1 percent) at Pine Stump.

Average population densities for the Black River and Pine Stump stands were 16,882 and 14,208/m², respectively (fig. 3). In both stands population densities appeared to peak in July. The highest densities observed were about 28,000/m² and 32,000/m² at Pine Stump and Black River, respectively.

Insecta: Diptera

Diptera or flies probably rank closely to the beetles in their importance in the soil-litter milieu (Wallwork 1970). Unlike the beetles, though, only the immature or larval stages of flies are functional members of the soil community. Adult flies usually leave the community and few feed within it. The primitive flies, Nematocera, are predominantly saprophagous or fungivorous. The more advanced Brachycera are predominantly predaceous, and the most advanced Cyclorropha are carrion feeders, coprophagous, saprophagous and parasitic. In general, Diptera require a very moist environment, so their abundance and importance decrease from moist to dry environments.

Twelve families of Diptera were identified from our soil samples (table 8, Appendix). This is a conservative estimate of the taxonomic diversity of Diptera because many immature specimens could not be identified (15 percent at Black River and 43 percent at Pine Stump). At Black River the most common flies were in order of decreasing abundance Bibionidae, Cecidomyiidae, and Stratiomyiidae. At Pine Stump, we found no Bibionidae in our samples but we knew they occur there. As at Black River the other two most abundant families were Cecidomyiidae and Stratiomyiidae. The soil dwelling form of these three families are probably all saprophages.

Black River had nearly four times (1,154 vs 428/m²) as many fly larvae as did Pine Stump. This difference was due to the great numbers of Bibionidae found at Black River but not at Pine Stump. Edwards (1974) reported a study of Diptera in Danish woodlands which found from 232 to 1,076 larvae/m².

Insecta: Hymenoptera

Ants (Formicidae) constitute the most important soil-litter dwelling forms of this order. They are common in a variety of environments; from deserts to moist woodlands. Feeding habits of ants are highly varied: carnivorous, phytophagous, fungivorous, xylophagous, saprophagous, and granivorous. All ants are soil insects and many develop nests within the ground. Through tunneling, carrying food, and culturing fungi, they (1) mix plant debris with soil material, (2) cause local increases in the abundance of some important nutrients, and (3) increase soil pore space and aggregate formation.

Twelve ant species were observed in one or both of the stands (table 9, Appendix). Most are woodland species. Two of the 12 were carpenter ants *Camponotus herculeanus* and *C. noveboracensis*. *C. herculeanus* was found only at Black River, but *C. noveboracensis* was common in both areas. We found nests of *C. noveboracensis* in standing-dead aspen trees. It is known to nest in fallen logs and occasionally within the soil proper (Wheeler and Wheeler 1963). Standing-dead aspen trees are almost invariably attacked and such hollowed trees are highly susceptible to wind breakage.

Dolichoderus taschemberg, a shiny black, medium sized ant, was found only in the Pine Stump stand. It forms very large colonies in wooded areas. We observed only two nests; both had concave mounds and were covered with bits of dead balsam fir needles, and other leaves.

Formica fusca and *F. marcida*, two very similar species in appearance and habits, were recorded from both stands.[4] Their nests are typically made in fallen logs, rotting stumps, or mounds of soil. However, most mounds were associated with decaying wood. *F. fusca* was more abundant of the two species.

F. ulkei, although not observed or collected in either stand, is present near the edge of the Black River stand in a field, and has the potential of moving into small openings within the forest (Wheeler and Wheeler 1963). It is included in this discussion because of its probable presence within this stand. It is a large red and black ant which builds rounded or conical mounds within the soil.

Lasius alienus, a small dark brown ant, was found only in the Black River stand, where it appears to be rare. This species prefers well shaded woodlands where it typically nests in rotting logs or stumps (Wheeler and Wheeler 1963).

Stenamma diecki, a small brown ant, prefers damp wooded areas where it builds small nests common in wood or leaf mold (Wheeler and Wheeler 1963). This ant was observed in small colonies in leaf mold on old, abandoned *Formica* spp. mounds. It is moderately common in both stands.

Tapinoma sessile, a small dark brown to black ant, was observed only once in the Black River stand. It appears to be rare. Wheeler and Wheeler (1963) state that probably no ant surpasses *T. sessile* in the diversity of its nesting sites.

Insecta: Mecoptera

The eruciform larvae of the panorpa group of common scorpion flies are active scavengers in the litter and upper soil layers. Their chief food is dead insects. The pupae are also rather active, and can move up through the soil to allow the adults to escape (Kevan 1962). These insects are temporary soil members. One *Panorpa helena* adult and one *P. subfurcata* adult were casually collected in June. Larvae were recovered only from pitfall traps — six from Pine Stump and only one from Black River.

Insecta: Orthoptera

The very common, but elusive, spotted camel cricket, *Ceuthophilus maculatus* (Gryllacrididae), was collected from pitfall traps in both stands. This insect is strictly nocturnal, spending the days hidden in dark moist places of the litter environment. According to the literature, it prefers the drier woodlands. Zoogeographic evidence suggests that the northern prairie belt was its original habitat. It is an omnivorous feeder (Hubbell 1936).

Nearly four times (51 vs. 14) as many crickets were recovered from Pine Stump as from Black River. Over twice as many males as females were recovered. Records indicate, however, that the sex ratio is typically equal so perhaps males were more prone to being trapped than females (Hubbell 1936). Immatures increased in numbers from June through August. For example, no immature individuals were recovered during June, only two were found in July, and eleven in August. The crickets overwinter primarily in the egg stage (Hubbell 1936).

Insecta: Psocoptera

Few members of this insect are actually litter-inhabiting. Accordingly they are probably of minor importance in the edaphic community. Members representing the suborders Eupsocida and Troctomorpha were recovered from both study stands. Winged eupsocids were the most abundant. All the Troctomorpha belonged to the family Liposcelidae and were taken from soil core samples. These individuals were wingless and probably belonged to the genus *Liposcelis*. They are probably litter-inhabiting.

Insecta: Thysanoptera

Many members of this order are transient soil-inhabitants. Some species spend their pupal stage in the soil whereas adults and larvae of still other species may hibernate in the upper soil or litter layers. Some thrips, however, are more closely tied

[4]*The* Formica fusca *group has recently been completely revised, but to date the work is not published. The identification of* F. fusca *and* F. marcida *are based on older work (personal communication with Dr. Gordon Ayre, 1973). We experienced a great deal of difficulty separating these species, and as a result, recorded them as one.*

to the litter environment because they feed on fungal hyphae or on small invertebrates (Kevan 1962). Members of this order probably contribute very little to the soil community. The few individuals recovered belonged to families Thripidae and Phloeothripidae.

Mollusca: Gastropoda

This phylum consists predominantly of marine organisms. Some have invaded the terrestrial environment apparently via the fresh water route. These are the common snails and slugs or Gastropods. The abundance and diversity of terrestrial molluscs appear to be greatest in woodland habitats but the greatest biomasses may occur in open grassland habitats (Mason 1974). Mollusc populations in brown earth and mature podzol soils are generally small ($<1/m^2$). However, where the soil is calcareous and loosely packed and surface vegetation is abundant, population densities may reach $60/m^2$ (Wallwork 1970). Terrestrial molluscs seem to exhibit a preference for calcareous, neutral to alkaline, soil-litter milieus.

Snails and slugs have diverse feeding habitats. Many are omnivorous or generalized feeders (Mason 1974); others are phytophagous, fungivorous, carnivorous, xylophagous, and saprophagous feeding on both plant and animal remains. Many genera of gastropods have cellulases, quite unlike most other terrestrial animals, so that they can break down and utilize the obiquitous cellulose in plant remains.

We recovered 13 species representing eight families of slugs and snails (table 10, Appendix). All are terrestrial species except one, *Lymnaeca catascorpium,* which is a freshwater snail. Both areas had eight species of snails and two species of slugs, but Pine Stump's snail population density was four-fold greater ($17/m^2$ vs. $4/m^2$) than Black River's based only on soil sieve samples.

Discus cronkhitei anthony, a small brown snail with heliciform shell, was the most abundant species comprising ~50 percent of the total snails found at Pine Stump (table 10, Appendix). It comprised less than 20 percent of the population at Black River. It is widely distributed throughout the eastern United States and southern Canada and prefers moist woodlands (Burch 1962). Generally it was found under debris on the forest floor.

The next most common and the largest snail at Pine Stump was *Succinea ovalis.* During the day it lives under leaves and other debris on the forest floor, but will often climb trees during wet weather (Baker 1939). Sample data indicate that its population density was $7/m^2$.

The three most common snails at Black River were *Cionella lubrica, D. cronkhitei* anthony, and *Retinella electrina* — altogether comprising about 75 percent of the individuals found.

Two species of slugs, *Ceroceras reticulatum* and *D. laeve,* were common in both stands. These species are not native to North America. They were recovered only from pitfall traps, so it was not possible to estimate their absolute population densities.

SUMMARY

The aspen forests in this study had substantial populations of small mesofauna and only meager populations of large mesofauna and macrofauna. In this respect, the aspen forests resembled mor rather than mull-like sites. For example, the myripods, isopods, molluscs, and lumbricid annelids, which are prominent in mull sites, were scarce in our study plots. Instead, the prominent organisms were mites, Collembolla, flies, and beetles. A scarcity of large burrowing mesofauna and macrofauna is usually reflected in a restricted distribution of soil organic matter, a lower degree of organo-mineral mixing, and lower amounts of crumb formation (Wallwork 1970). This was certainly evident at Pine Stump but not so at Black River, presumably because of the presence of the burrowing earthworm, *Allolobophora trapezoides,* and greater numbers of burrowing millipedes.

Both study plots had similar numbers of soil invertebrates, as shown in the tabulation below, but the species compositions were slightly different.

Soil invertebrates	Black River stand	Pine Stump stand
	(mean numbers/m²)	
Lumbricidae	70	124
Acari	87,214	93,653
Araneida	10	25
Chelonethida	108	313
Diplopoda	4	1
Chilopoda	6	5
Coleoptera	433	327
Collembola	19,157	14,108
Diptera	1,505	427
Mollusca	4	17

For example, Pine Stump had more individuals of those species that were acid tolerant, *(Dendrobeana* spp., *Microbisium brunneum)* and fewer of those that were hydrophilous or very sensitive to desiccation (Lithobiomorpha centipedes, polydesmid millipedes, etc.).

Soil pH samples revealed that the soils at Black River were more basic and less acid than soils at Pine Stump. In addition, the vegetation and general observation indicated that Black River soils were wetter and less subject to desiccation during the summer months. These conditions probably account for the differences in species composition between study plots.

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APPENDIX

Table 1. — ***Average soil depth*[1] *and pH and their respective ranges for the 01 (undecomposed litter), the 02 (decomposed organic material down to the humus layer), the A2 (mineral surface soil), and the B (subsoil) horizons for each quadrat of both study stands***

Soil horizon characteristics	Q1	Q2	Q3	Q4	Stand mean
BLACK RIVER STAND					
01 Horizon					
$\bar{x}$ Depth (cm)	1.44	1.44	1.34	1.41	1.41
Range (cm)	0.5-8.0	0.5-8.5	0.5-4.5	0.5-7.0	0.5-8.5
02 Horizon					
$\bar{x}$ Depth (cm)	8.91	7.98	8.98	8.10	8.49
Range (cm)	2.5-24.0	3.0-23.0	6.0-15.0	5.0-15.0	2.5-24.0
$\bar{x}$ pH	6.70	6.55	6.50	6.62	6.59
Range	6.0-7.2	6.2-7.0	6.0-7.0	6.0-7.0	6.0-7.2
A2 Horizon					
$\bar{x}$ Depth (cm)	15.98	15.29	13.28	12.67	14.31
Range (cm)	0.0-23.0	0.0-27.0	0.0-24.0	0.0-21.0	0.0-27.0
$\bar{x}$ pH	6.80	6.48	6.66	6.63	6.64
Range	5.7-7.5	6.2-6.7	6.0-7.5	6.2-7.0	5.7-7.5
B Horizon					
$\bar{x}$ pH	7.87	7.50	7.52	7.72	7.65
Range	7.5-8.0	7.0-8.0	7.0-8.0	6.7-8.0	6.7-8.0
PINE STUMP STAND					
01 Horizon					
$\bar{x}$ Depth (cm)	4.00	3.17	2.80	3.57	3.39
Range (cm)	2.0-8.0	0.5-7.0	1.0-5.5	1.5-5.5	0.5-8.0
02 Horizon					
$\bar{x}$ Depth (cm)	8.27	5.94	5.43	5.97	6.40
Range (cm)	3.5-24.0	0.0-14.0	0.0-14.5	0.0-9.0	0.0-24.0
$\bar{x}$ pH	6.00	5.90	6.28	6.20	6.10
Range	5.8-6.3	4.5-6.0	5.2-7.0	6.0-7.0	4.5-7.0
A2 Horizon					
$\bar{x}$ Depth (cm)	12.31	11.60	10.04	9.63	10.90
Range	0.0-23.0	0.0-21.0	0.0-16.0	0.0-14.5	0.0-23.0
$\bar{x}$ pH	6.05	5.36	5.88	5.60	5.72
Range	5.8-6.3	4.8-6.0	5.5-6.1	5.5-6.0	4.8-6.3
B Horizon					
$\bar{x}$ pH	7.00	6.30	6.14	5.50	6.24
Range	5.5-8.0	5.3-8.0	5.5-6.8	4.8-6.0	4.8-8.0

[1]Soil depth averages are based on the number of occurrences recorded for any given horizon.

Table 2. — ***Forest stand table showing numbers and basal areas of different tree species at Black River and Pine Stump study plots***

Tree stocking	Tree species: *Populus tremuloides*	*Populus balsamifera*	*Abies balsamea*	*Betula papyrifera*	*Fraxinus nigra*	Totals/ acre
BLACK RIVER						
Number of stems/acre	584.0	75.0	92.0	--	89.0	840.0
Basal area/acre	101.0	12.0	.5	--	2.5	116.0
PINE STUMP						
Number of stems/acre	736.0	25.0	33.0	54.0	--	848.0
Basal area/acre	91.0	2.5	1.5	2.0	--	97.0

Table 3. — *A systematic list of all invertebrates found (identified to the lowest taxon possible)*

PHYLUM ANNELIDA
Class Oligocheata
Order Opisthopora
Family Lumbricidae
Allolobophora trapezoides
Dendrobaena octaedra
D. rubida
Octolasion tyrtaeum

PHYLUM ARTHROPODA
Class Arachnida
Order Acari
Suborder Acaridei (=Astigmata)
Superfamily Acaroidea
Family Acaridae
Tyrophagus sp.
Superfamily Anoetoidea
Family Anoetidae
Histiosoma sp.
Suborder Mesostigmata
Superfamily Parasitoidea
Family Ascidae
Asca aphidioides
A. garmani
Family Crytolaelapidae
Gamasellus sp.
Family Digamasellidae
Digamasellus sp.
Family Laelapidae
Hypoaspis sp.
Family Phytoseiidae
Amblyseius krantzi
Family Podocinidae
Podocinum pacificum
Family Zerconidae
Parazercon radiata
Zercon sp.
Superfamily Sejoidea
Family Sejidae
Sejus sp.
Suborder Oribatei (=Cryptostigmata)
Superfamily Carabodoidea
Family Tectocepheidae
Tectocepheus velatus
Superfamily Cepheoidea
Family Cepheidae
Cepheus corae
Superfamily Ceratozetoidea
Family Ceratozetidae
Ceratozetes sp.
Fuscozetes bidentatus
Propelops sp.
Superfamily Damaeoidea
Family Belbidae
Belba sp.
Superfamily Hypochthonoidea
Family Brachychthoniidae
Brachychthonius semiornatus
Brachychthonius sp.
Liochthonius sp.
Synchthonius crenulatus
Family Eniochthoniidae
Hypochthoniella borealis
Superfamily Mesoplophoroidea
Family Mesoplophoridae
Archoplophora laevis
Superfamily Nothroidea
Family Camisiidae
Platynothrus sp.
Family Malaconothridae
Malaconothrus sp.
Family Nothridae
Nothrus sp.
Superfamily Oppioidea
Family Oppiidae
Oppia sp.
Oppiella nova
Quadroppia sp.
Family Suctobelbidae
Suctobelba (2 spp.)
Superfamily Oribatelloidea
Family Achipteriidae
Anachipteria sp.
Superfamily Oribatuloidea
Family Haplozetidae
Xylobates sp.
Family Oribatulidae
Scheloribates sp.
Family Oripodidae
Oripoda sp.

Superfamily Phthiracaroidea
Family Phythiracaridae
Phthiracarus setosellum
Steganacarus diaphanum
Superfamily Zetorchestoidea
Family Gustaviidae
Gustavia sp.
Suborder Prostigmata
Superfamily Bdelloidea

Family Cunaxidae
Cunaxa sp.
Superfamily Eupodoidea
Family Eupodidae
Cocceupodes (2 spp.)
Eupodes sp.
Family Rhagidiiae
Coccorhagidia sp.
Rhagidia longisensilliba
Rhagidia sp.
Superfamily Pachygnathoidea
(=Endeostigmata)
Family Alicorhagiidae
Alicorhagia sp.
Family Pachygnathidae
Bimichaelia sp.
Pachygnathus sp.
Superfamily Tarsonemoidea
(=Tarsonemini)
Family Pyemotidae
Bakerdania sp.
Microdispus obovatus
Family Scutacaridae
Scutacarus sp.
Family Tarsonemidae
Tarsonemus sp.
Order Araneida
Order Chelonethida (=Pseudoscorpionida)
Suborder Diploshyronida
Family Neobisiidae
Microbisium brunneum
M. confusum
Suborder Heterosphyronida
Family Chthoniidae
Mundochthonius rossi
Order Phalangida
Suborder Palpatores
Family Ischyropsalidae
Sabacon crassipalpe
Family Nemastomatidae
Crosbycus dasycnemus
Family Phalangidae
Leiobunum calcar
L. politum Weed
L. ventricosum
Odiellus pictus pictus
Class Chilopoda
Order Geophilomorpha
Order Lithobiomorpha
Class Crustacea
Order Eucopepoda
Class Diplopoda
Order Polydesmida
Class Insecta
Order Coleoptera
Suborder Adephaga
Family Carabidae
Agronum decentis
A. gratiosum
A. mutatum
A. puncticeps
A. retractum
Synuchus impunctatus
Bembidion sp.
Calosoma frigidum
Sphaeroderus lecontei
Acupalpus sp.
Bradycellus sp.
Harpalus pleuriticus
Harpalus sp.

Lebi tricolor
Badister sp.
Badister reflexus
Pterostichus adstrictus
P. coracinus
Trechus apicalis
Family Noteridae
Suborder Polyphaga
Superfamily Cantharoidea
Family Cantharidae
Cantharis fraxini
C. nigriceps
Family Lampyridae
Ellychnia corrusca autumnalis
Superfamily Chrysomeloidea
Family Chrysomelidae
Altica maybe *ignita*
Crepidodera nana
Oedionychis subvittata
Phratora americana
Bassareur mammifer sellatus
Superfamily Cucujoidea
Family Endomychidae
Danae testacea
Family Erotylidae
Triplax thoracica
Family Lathridiidae
Melanophthalma sp.
Family Nitidulidae
Epuraea rufa
Superfamily Curculionoidea
Family Curculionidae
Brachyrhinus ovatus
Superfamily Elateroidea

Family Elateridae
Dalopius sp.
Superfamily Hydrophiloidea
Family Histeridae
Hister depurator
Family Hydrophilidae
Anacaena sp.
Cymbiodyta fimbriata
Hydrobius fuscipes
Superfamily Scarabaeoidea
Family Scarabaeidae
Aphodius fimetarius
Aphodius sp.
Geotrupes semiopacus
Superfamily Staphylinoidea
Family Leiodidae
Anisotoma sp.
Family Leptodiridae
Colon sp.
Family Orthoperidae
Family Pselaphidae
Family Ptiliidae
Family Staphylinidae
Lathrobium probably *brevipenne*
L. probably *simplex*
Lathrobium sp.
Rugilus dentatus
Ontholestes cingulata
Philonthus cyanipennis
P. lomatus
P. probably *micans*
Philonthus sp.
Quedius molochinus
Q. peregrinus
Staphylinus badipes
Lordithon cincticollis
Lordithon sp.
Bryoporus rufescens
Tachinus pallipes
Tachyporus maybe *elegan*
Tachyporus spp.
Family Silphidae
Nicrophorus sayi
N. tomentosus
N. vespilloides
Superfamily Tenebrionoidea
Family Alleculidae
Isomira quadristriata
Order Collembola
Suborder Arthropleona
Superfamily Entomobryoidea
Family Entomobryidae
Entomobrya quinquelineata
E. unostrigata
Entomobryoides purpurascens
Lepidocyrtus lignorum
L. paradoxus
L. violaceous
Orchesella ainsliei
Willowsia buski
W. plantani nigromaculata
Family Isotomidae
Anurophorus laricus
Isotoma near *finitima*
I. muskegis
I. nigrifrons
I. notabilis
I. olivacea
I. trispinata
I. viridis
Isotominella minor
Folsomia candida
Guthriella vetusta
Proisotoma minuta
Family Tomoceridae
Tomocerus flavescens
T. vulgaris
Superfamily Hypogastruroidea
Family Hypogastruridae
Hypogastrura nivicola
Family Onychiuridae
Hymenaphorura similis
Protaphorura pseudarmatus
Tullbergia collis
Suborder Neoarthropleona
Family Anuridae
Anurida tullbergi
Aphoromma granaria
Family Neanuridae
Micranurida pygmaea
Neanura muscorum
Pseudachorutes aureofasciatus
Suborder Symphypleona
Family Neelidae
Megalothorax albus
Neelus minutus
Family Sminthuridae
Arrhopalites benitus
Sminthurinus sp.
Sphyrotheca minnesotensis
Ptenothrix marmorata
Sminthurides lepus
S. occultus
Order Diptera
Suborder Brachycera
Superfamily Empidoidea

Family Dolichopidae
Family Empididae
Superfamily Tabanoidea
Family Stratiomyiidae
Family Tabanidae
Suborder Cyclorrhapha
Superfamily Muscoidea
Family Anthomyiidae
Fannia sp.
Family Muscidae
Superfamily Oestroidea
Family Sarcophagidae
Family Tachinidae
Superfamily Phoroidea
Family Phoridae
Superfamily Sciomyzoidea
Family Dryomyzidae
Superfamily Syrphoidea
Family Syrphidae
Microdon sp.
Family Helemoyzidae
Suborder Nematocera
Superfamily Bibionoidea
Family Bibionidae
Superfamily Culicoidea
Family Chironomidae (=Tendipedidae)
Family Culicidae
Family Simuliidae
Superfamily Mycetophiloidea
Family Cecidomyiidae
Family Sciaridae
Superfamily Tipuloidea
Family Tipulidae
Order Hemiptera
Suborder Geocorizae
Family Aradidae
Family Largidae
Family Miridae
Family Nabidae
Family Pentatomidae
Family Tingidae
Order Homoptera
Suborder Auchenorrhyncha
Superfamily Cicadoidea
Family Cercopidae
Family Cicadellidae
Superfamily Fulgoroidea
Family Delphacidae
Suborder Sternorrhyncha
Superfamily Aphidoidea
Family Aphididae
Superfamily Coccidea
Family Coccoidea
Superfamily Psylloidea
Family Psyllidae
Order Hymenoptera
Suborder Apocrita
Superfamily Cynipoidea
Family Cynipidae
Superfamily Ichneumonoidea
Family Braconidae
Bracon sp.
Meteorus sp.
Macrocentrus sp.
Apanteles sp.
Family Ichneumonidae
Pleolophus indistinctus
Gelis sp.
Phygadeuon spp.
Phaeogenes sp. s.l.
Cratichneumon sp.
Vulgichneumon terinalis
Dialipsis communis
Oxytorus antennatus
Orthocentrus spurius
O. frontator
Picrostigeus sp.
Stenomacrus sp.
Hyposoter popofensis
Coccygomimus pedalis
Ephialtes annulicornis
Aniseres sp.
Hyperacmus crassicornis
Megastylus sp.
Chriodes sp.
Superfamily Proctotrupoidea
Family Diapriidae
Family Platygasteridae
Family Proctotrupidae (=Serphidae)
Family Scelionidae
Superfamily Scoliodea
Family Formicidae
Dolichoderus taschenbergi
Tapinoma sessile
Camponotus herculeanus
C. noveboracensis
Formica fusca
F. marcida
F. probably *sanquinea subnuda*
F. ulkei
Lasius alienus
Myrmica probably *brevinodis*
M. probably *emeryana*
Stenamma diecki
Superfamily Tenthredinoidea

Family Tenthredinidae
Superfamily Vespoidea
Family Pompilidae (=Psammocharidae)
Family Vespidae
Vespula sp.
Order Lepidoptera
Superfamily Geometroidea
Family Geometridae
Superfamily Noctuoidea
Family Artiidae
Family Noctuidae
Superfamily Sphingoidea
Family Sphingidae
Superfamily Pyralidoidea
Family Pyralidae
Order Mecoptera
Family Panorpidae
Panorpa helena
P. subfurcata
Panorpa sp.
Order Orthoptera
Suborder Caelifera
Family Acrididae
Melanopus islandicus
Suborder Ensifera
Family Gryllacrididae
Ceuthophilus macultus
Order Psocoptera
Suborder Eupsocida
Suborder Troctomorpha
Family Liposcelidae
Liposcelis sp.
Order Thysanoptera
Suborder Terebrantia
Family Thripidae
Suborder Tubulifera
Family Phloeothripidae

PHYLUM MOLLUSCA
Class Gastropoda
Order Basommatophora
Family Carychiidae
Carychium exiguum
Order Pulmonata
Family Lymnaeidae
Lymnaea catascorpium
Order Stylommatophora
Suborder Heterurethra
Family Succineidae
Succinea ovalis
Suborder Orthurethra
Family Cionellidae
Cionella lubrica
Family Strobilopsidae
Strobilops labyrinthica
Suborder Sigmurethra
Family Endodontidae
Anguispira altermata
Discus cronkhitei anthonyi
Family Limacidae
Deroceras reticulatum
D. laeva
Family Zonitidae
Euconulus fulvus
Retinella electrina
Vitina limpida Gould
Zonitoides arboreus

PHYLUM NEMATODA

Table 4. — *Spiders occurring in different quadrats of both study stands — based on soil block sieve samples*

Month of sampling	Quadrats Q1	Q2	Q3	Q4	Average per quadrat
BLACK RIVER STAND					
	- - - - *number/m²* - - - -				
June	10.8	6.5	21.6	13.0	13.0
July	8.7	8.7	6.5	8.7	8.1
August	8.7	0.0	17.3	4.3	7.6
Average/month	9.4	5.0	15.1	8.7	9.6
PINE STUMP STAND					
June	26.0	34.6	8.7	36.8	26.5
July	34.6	17.3	32.5	23.8	27.1
August	13.0	21.6	28.1	21.6	21.1
Average/month	24.5	24.5	23.1	27.4	24.9

Table 5. — *Beetle larvae collected in each study stand — based on soil sieve and Tullgren funnel extraction methods*
(In number/m^2)

Families of juvenile beetles	Sieving method: Black River stand	Sieving method: Pine Stump stand	Funnel method: Black River stand	Funnel method: Pine Stump stand
Cantharidae	0.7	0.0	72.1	114.6
Carabidae	2.9	1.4	21.6	30.6
Chrysomelidae	0.2	0.0	0.0	0.0
Curculionidae	0.2	0.0	0.0	0.0
Elateridae	1.8	9.7	14.4	68.7
Lampyridae	0.7	1.1	0.0	0.0
Orthoperidae	0.0	0.0	14.4	0.0
Scarabaeidae	4.9	0.4	0.0	0.0
Silphidae	0.0	0.2	0.0	0.0
Staphylinidae	2.5	2.9	64.9	30.6
Unknown larvae	0.0	0.0	245.1	84.0
Total larvae	13.9	15.7	432.5	328.0
Total pupae	1.3	1.1	0.0	0.0

Table 6. — *Beetle larvae occurring in different quadrats of both study stands — based on soil block sieve and Tullgren funnel extraction methods*

Month	Sampling method[1]	Quadrats: Q1	Q2	Q3	Q4	Average per quadrat
BLACK RIVER STAND						
		- - - Number/m^2 - - -				
June	SM	4	11	15	13	11
	FM	183	0	513	513	310
Julv	SM	6	17	6	15	11
	FM	428	684	855	257	556
August	SM	6	11	54	6	19
	FM	257	1,112	257	85	428
Average/month	SM	6	13	25	11	14
	FM	292	612	542	285	432
PINE STUMP STAND						
June	SM	24	19	30	15	22
	FM	99	275	183	513	275
July	SM	26	15	13	19	18
	FM	275	642	0	257	293
August	SM	11	4	9	2	6
	FM	513	275	642	275	420
Average/month	SM	20	13	17	12	16
	FM	305	397	257	350	328

[1] SM = Sieving Method; FM = Funnel Method.

Table 7. — *Collembolan species found within Tullgren core samples in both study stands* (In number/m²)

Species	Black River	Pine Stump
Family Entomobryidae:		
Entomobrya quinquelineata	21	21
E. unostrigata	0	21
Lepidocyrtus lignorum	86	150
L. paradoxus	0	21
L. violaceous	257	0
Orchesella ainsliei	0	21
Willowsia buski	235	278
W. platani nigromaculata	64	0
Family Isotomidae:		
Anurophorus laricus	21	364
Isotoma near finitima	86	257
I. nigrifrons	0	21
I. notabilis	364	471
I. olivacea	385	1,797
I. trispinata	150	471
I. viridis	107	86
Isotominella minor	21	0
Folsomia candida	2,459	2,652
Guthriella vetusta	1,133	0
Proisotoma minuta	21	150
Family Tomoceridae:		
Tomocerus flavescens	321	299
T. vulgaris	684	86
Family Hypogastruridae:		
Hypogastrura nivicola	0	235
Family Onychiuridae:		
Hymenaphorura similis	64	278
Protaphorura pseudarmatus	86	0
Tullbergia collis	2,951	941
Family Anuridae:		
Anurida tullbergi	43	21
Aphoromma granaria	107	428
Family Neanuridae:		
Micranurida pygmaea	43	86
Neanura muscorum	21	0
Pseudachorutes aureofasciatus millsi	21	0
Family Neelidae:		
Megalothorax albus	299	171
Neelus minutus	43	21
Family Sminthuridae:		
Arrhopalites benitus	1,155	620
Sphyrotheca minnesotensis	21	0
Ptenothrix marmorata	21	0
Sminthurides lepus	0	86
S. occultus	171	0

Table 8. — *Fly larvae by family for each study stand and sampling method*
(In number/m²)

Families of fly larvae	Funnel method		Sieving method	
	Black River Stand	Pine Stump Stand	Black River Stand	Pine Stump Stand
Anthomyiidae	7	8	--	--
Bibionidae	1,009	--	3.0	--
Cecidomyiidae	209	92	--	--
Chironomidae	--	15	--	--
Dolichopidae	--	--	--	1
Muscidae	--	--	0.5	1
Sciaridae	--	--	--	4
Stratiomyiidae	36	115	--	--
Tabanidae	14	8	--	2
Tipulidae	--	8	0.2	3
Unknowns	238	183	0.4	1
Total larvae	1,514	428	4.0	12

Table 9. — *Ant species collected by different sample methods*[1]

Ant Species	Pitfall Method		Sieving Method		Total Observations		Field Observations	
	Black River stand	Pine Stump stand	Black River stand	Pine Stump stand	Black River stand	Pine Stump stand	Black River stand	Pine Stump stand
Camponotus herculeanus	1	0	0	0	1	0	[2]-	-
C. noviboracensis	12	2	0	1	12	3	[3]+	+
Dolichoderus taschenbergi	0	1	0	2	0	3	-	2
Formica fusca + F. marcida	15	10	0	1	15	11	+	+
F. probably sanguinea subnuda	1	4	0	0	1	4	-	-
F. ulkei	0	0	0	0	0	0	1	-
Lasius alienus	3	0	0	0	3	0	-	-
Myrmica probably brevinodis	6	0	0	1	6	1	-	-
M. probably emeryana	14	15	15	8	29	23	+	+
Stenamma diecki	0	2	0	2	1	5	-	-
Tapinoma sessile	0	0	0	0	0	0	1	-

[1]The Tullgren Funnel Method is not listed separately but its results are included in the total observation column.

[2]- = No field observations.

[3]+ = A number of specimens casually observed in the field during the summer but not counted.

Table 10. — *Gastropoda species collected by different sampling methods in both study stands*

Gastropod species	Pitfall method		Sieving method[1]	
	Black River stand	Pine Stump stand	Black River stand	Pine Stump stand
Anguispira alternata	0	0	1	0
Carychium exiguum	0	0	0	0
Cionella lubrica	0	0	9	4
Detoceras reticulatum	4	14	0	0
D. laeve	34	14	0	0
Discus cronkhitei anthonyi	3	68	5	46
Euconulus fulvus	0	1	0	0
Lymnaea catascorpium	0	0	1	0
Retinella electrina	5	9	4	11
Strobilops labyrinthica	0	9	0	0
Succinea ovalis	2	11	1	37
Vitrina limpida	0	0	[2]+	+
Zonitoides arboreus	0	0	1	0

[1]The soil block sieving method did not select for most snails in a very precise manner. All snails, except *Succinea ovalis*, were small and occupied a niche not easily accessible by this technique. Therefore, the numbers representing each species for this method are not very accurate. They do, however, represent a datum to fix relative abundance to. Due to its large size, the numbers representing *S. ovalis* for this technique should be considered accurate.

[2]+= Sample location information lost for the three specimens found.

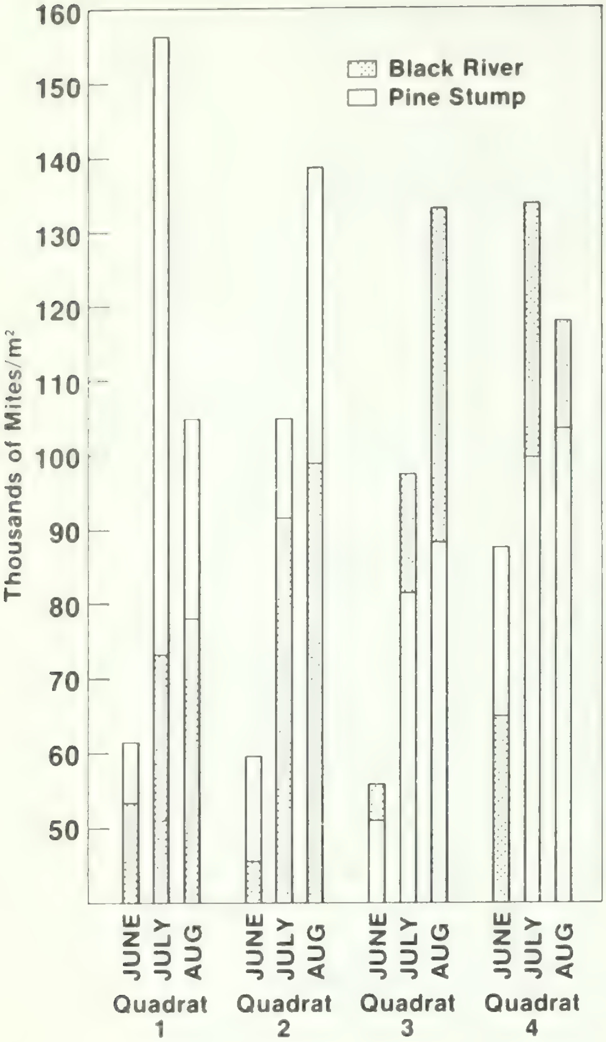

Figure 1. — *Mean numbers of mites in different quadrats at Black River and Pine Stump during June, July, and August — based entirely on Tullgren core samples.*

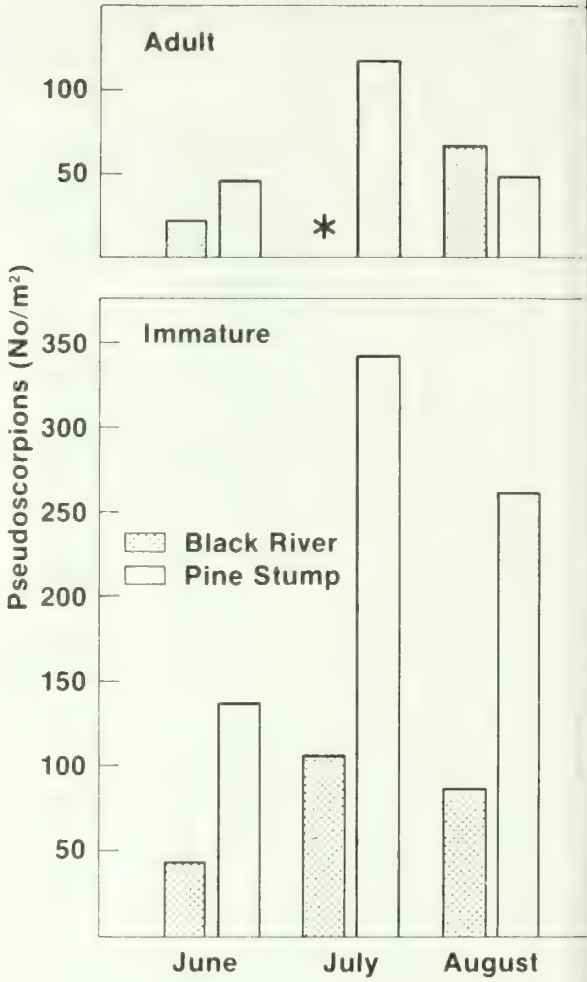

Figure 2. — *Mean numbers of adult and immatu[...] pseudoscorpions in Black River and Pine Stum[...] stands during June, July, and August — based o[...] Tullgren samples.*

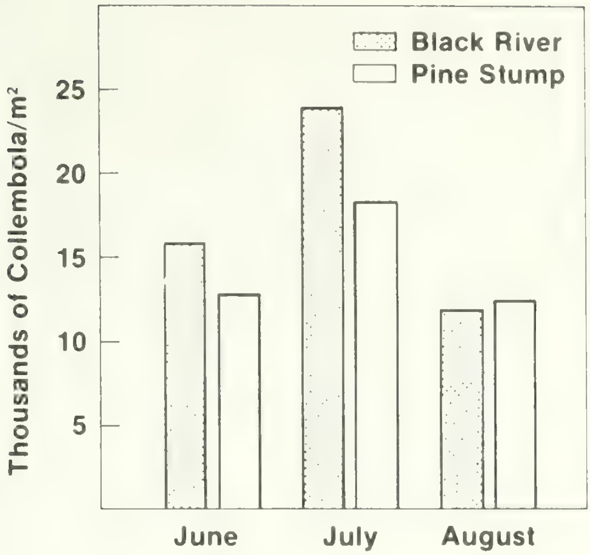

Figure 3. — *Mean numbers of Collembola in Black River and Pine Stump stands during June, July, and August — based on Tullgren samples.*

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Wagner, T. L., W. J. Mattson, and J. A. Witter.
1977. A survey of soil invertebrates in two aspen forests in northern Minnesota. USDA For. Serv. Gen. Tech. Rep. NC-40, 23 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The survey in Koochiching County revealed 4 phyla, 7 classes, 23 orders, and 134 families of invertebrates. Insecta was the largest class having 11 orders and 84 families. Mites and Collembolla were most numerous averaging 90,000 and 16,000/m^2, respectively, during summer.

OXFORD: 114.68:142(776). KEY WORDS: Mites, Collembolla, Molluscs, earthworms, *Populus*.

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Nature is beautiful...leave only your footprints.

USDA FOREST SERVICE
GENERAL TECHNICAL REPORT NC-41

an annotated bibliography on river recreation

EXPERIMENT STATION

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Forest Service - U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108

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1978

CONTENTS

AN ANNOTATED BIBLIOGRAPHY ON RIVER RECREATION

Compiled by

Dorothy H. Anderson and
Earl C. Leatherberry, *Associate Geographers*,
and David W. Lime, *Principal Geographer*

During the past 10 years there has been a phenomenal growth in the number of people participating in water recreation activities in the United States. One of the most striking examples of this growth is on our Nation's rivers. For example, boating activities have increased 100 percent during the last decade on the Allagash River in Maine, the Pine River in Michigan, and the Rogue River in Oregon.

Along with the growth in the number of people using river recreation resources has come a growing interest on the part of administrators, planners, managers, researchers, and the public to learn more about these resources. Their interest is evidenced partly by the ever increasing volume of literature about river-based recreation. Concern and excitement about river recreational resources is evidenced further by the response at a recent international symposium on river recreation.

The Symposium, River Recreation Management and Research, sponsored by the North Central Forest Experiment Station's Backcountry River Recreation Management Research Project, was held in Minneapolis, Minnesota, January 24-27, 1977. About 400 participants representing 44 States and 5 Canadian Provinces attended the meeting. A significant product of this conference is a published proceedings[1] containing 55 formal papers on various aspects of river recreation. All of these papers have been cited and annotated in this bibliography.

Most of the literature about river recreation has been published since 1968. Also, much of the literature can be characterized as: (1) involving one-time studies without followup research to identify trends; (2) consisting of one-river case studies not comparable with other river studies; (3) emphasizing descriptive rather than process-causal analysis of river problems; (4) focusing on Western whitewater rivers unique in both location and management; and (5) concentrating on a single on-river activity during a specific time of the year.

An important criterion used to determine whether or not a publication was included in the bibliography was its availability. Most materials are available in depository libraries or can be obtained from the authors. A few reports, such as doctoral dissertations and some Water Resources Institute publications, may be difficult to obtain but are included because of the knowledge they contribute to understanding various aspects of the river recreation resource.

The Bibliography references materials were collected through December 14, 1977.

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[1] USDA Forest Service. 1977. River recreation management and research. USDA For. Serv. Gen. Tech. Rep. NC-28, 455 p., illus. North Central For. Exp. Stn., St. Paul, MN.

The bibliography is organized into nine parts. Within each one papers are arranged alphabetically by author. Many of the references are cited in more than one part. Therefore, all references are numbered. If a reference is relevant to more than one section, it appears with its annotation in the first appropriate one and is referenced by number only at the beginning of all other relevant sections. As an aid to locating references, an author index is provided at the end of the bibliography.

Part one lists several annotated bibliographies covering topics such as carrying capacity, landscape aesthetics, fishing, and the socio-economic aspects of water resources relevant to management and research of water-based recreation.

Part two includes references that provide a broad overview of the role rivers play in outdoor recreation. Articles describe the diversity of river recreation opportunities, document the need for research, recount attempts of State and Federal governments to preserve rivers through legislation, and report on problems encountered by recreation users, river managers, landowners, and others.

Methods to inventory and classify river recreation resources are presented in part three. River resources can be classified by any number of variables such as user landscape preferences, physical characteristics of the river environment, level of experience needed to float a river, and types of activities prevalent on a river or in the river corridor.

Part four cites economic methods to evaluate alternative uses of river resources. Articles cited examine the economic benefits the recreation user enjoys by supporting such programs as stocking rivers with game fish and the economic benefits realized by private entrepreneurs who provide recreation users with facilities such as campgrounds, boat docks, and places near the river for recreation equipment rentals. Benefits such as increased employment and commercial development local communities may receive as a result of preserving local rivers for recreation are discussed also.

Articles cited under part five describe investigations of the impacts that people or the recreation activity have on river resources such as the effects of trampling on streambank erosion and vegetation, the impacts of gasoline motors on water quality, and the consequences of littering to the aesthetics of the river environment.

Part six focuses on how rivers are used and by whom. Users have been identified by their socio-economic characteristics, preferences for specific kinds of recreational activities or settings, motivations for engaging in water recreation pursuits, and behavior they exhibit while recreating on and along rivers.

Techniques such as site management, rationing, zoning, and site maintenance and rehabilitation to manage both the user and the river resource to meet desired management objectives are cited in part seven.

Part eight contains an unannotated chronological listing of all Federal legislation pertaining to the National Wild and Scenic Rivers Act of 1968.

An unannotated listing of selected guidebooks on rivers of North America is contained in part nine. All include descriptive information about rivers, which aids in defining the role of rivers as recreational resources.

ACKNOWLEDGMENT

We wish to express our appreciation to Lorinda Anderson, former student at the University of Minnesota; Alfred Buck, retired from the Bureau of Outdoor Recreation; Richard Hecock, Oklahoma State University; and, Clay E. Peters, Staff Consultant, Committee on Interior and Insular Affairs, U.S. House of Representatives for their assistance in the preparation of the Bibliography.

[1]

BIBLIOGRAPHIES PERTINENT TO WATER RESOURCE MANAGEMENT AND RESEARCH

1. Arthur, Louise M., and Ron S. Boster. 1976. Measuring scenic beauty: a selected annotated bibliography. USDA For. Serv. Gen. Tech. Rep. RM-25, 34 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colorado.

Contains 167 references, most of which date from 1965. Papers are categorized into: (1) literature review, (2) inventory methods, (3) public involvement, or (4) miscellaneous. Many annotations include a "critical comment".

2. Ditton, Robert B. 1969. The identification and critical analysis of selected literature dealing with the recreational aspects of water resources use, planning, and development. Res. Rep. 23, 293 p. Univ. Illinois. Water Resour. Cent., Urbana, Illinois.

Describes how more than 1,000 articles and publications were identified, documented, and classified according to keyword descriptors. A computerized bibliographic retrieval routine was developed to enable an investigator to receive relevant bibliographic notations. Using this retrieval system to assemble bibliographies by topic, this project surveyed and analyzed research findings and their implications for water recreation planning and development. An interdisciplinary water recreation planning and development bibliography is included.

3. Hamilton, H. R., D. H. Owens, J. E. Carroll, A. R. Glenn,and B. A. Gilmour. 1966. Bibliography on socio-economic aspects of water resources. 453 p. USDI Office of Water Resour. Res., Washington, D.C.

Contains 770 annotations of papers, most of which were published between 1955 and 1965. Includes literature in the following areas: (1) supply of and demand for water of various qualities including the competitive use for industry, domestic, and recreation; (2) method and application of cost/benefit analysis; (3) economic impact of water resource and water development projects; (4) methods of determining the economic value of sport fisheries, wildlife, and other aquatic outdoor recreation resources; and (5) social values of water-based outdoor recreation.

4. Potter, Dale R., Kathryn M. Sharpe, and John C. Hendee. 1973. Human behavior aspects of fish and wildlife conservation: an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. PNW-4, 287 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

Contains 995 references from 218 different sources on nonbiological or human behavior aspects of fish and wildlife conservation. Includes papers on sportsman characteristics, safety, law enforcement, professional and sportsman education, nonconsumptive uses, economics, and history. Also includes a categorized summary of reference sources.

5. Potter, Dale R., Kathryn M. Sharpe, John C. Hendee, and Roger N. Clark. 1972. Questionnaires for research: an annotated bibliography on design, construction, and use. USDA For. Serv. Res. Pap. PNW-140, 80 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oregon.

Questionnaires as social science tools are used increasingly for studying the human aspects of outdoor recreation and other natural resource fields. An annotated bibliography including subjective evaluations of each article and a keyword list is presented for 193 references to aid researchers and managers in the design, construction, and use of mail questionnaires.

6. Stankey, George H., and David W. Lime. 1973. Recreational carrying capacity: an annotated bibliography. USDA For. Serv. Gen. Tech. Rep. INT-3, 45 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Contains more than 200 references covering recreational carrying capacity problems. Contents are categorized into concept, biology, aesthetics, and management.

7. Alexander, Harold E. 1965. The state's role in stream preservation. Naturalist 16(3):26-29.

Suggests that stream preservation efforts are based on perpetuation of intangible values, both aesthetic and scenic, that contribute to the scope and quality of the human environment. Believes previously used criteria for assigning values to intangibles are inadequate because States continue to lose ground to development interests.

8. Alling, Curtis Edwin. 1977. An identification and analysis of the critical obstacles encountered in the creation of State natural rivers programs. M.S. thesis. Dep. of Recreation and Parks, Texas A&M Univ., College Station, Texas. 71 p.

Data collected from 40 States that have taken recent action to protect natural river systems was analyzed to identify and try to devise methods to overcome the obstacles encountered by State agencies as a result of their actions to establish natural river programs. Four principle obstacles were: (1) opposition of the local community, (2) lack of administrative support from higher levels of State government, (3) competition for the river corridor resources with other uses, and (4) lack of visible constituents to offer support. Methods are suggested to overcome these obstacles. Concludes that no one alternative is a solution for overcoming the obstacles, and that each area should be dealt with individually.

9. Alston, Farnum, and Bob Deer. 1975. The Wolf River--an uncertain future. Naturalist 26(1):13-15, 18.

Details the history of Menominee Indian's management practices and use of the Wolf River in northeastern Wisconsin. Discusses land tenure changes, State leasing of land for public access and use, and current conflicts over inclusion of Wolf River in the National Wild and Scenic River System.

10. Bock, William, and Frank Thomas. 1974. A look at the Wild and Scenic Rivers Act. Tech. Assist. Pap. Ser. B, Pap. 1, 18 p. USDI Bur. Outdoor Recreation.

A quick reference guide consisting of two parts: (1) self-explanatory outline of the Act, and (2) legal opinions that answer frequently asked questions about the interpretation of the various sections and phrases of the Act.

11. Brittain, Robert. 1958. Rivers and man. 288 p. Longsman, Green & Co., London.

Develops the idea that rivers are intimately involved in every stage of human development. Traces the stages of man's mastery over rivers and the resultant changes in human society. Relates ancient uses of rivers that contributed to man's progress: fishing, agriculture, urban water systems, trade, and water power.

12. Brockman, Frank C. 1961. Recreation and water in the west. *In* Water Resources papers 1960: water-measuring and meeting future requirements. Harold L. Amos, ed. Univ. Colorado, Boulder, Colorado.

Outlines the history of increasing interest in public recreation lands in the United States. Notes that conflicts in priorities arise, especially in the western States, between recreation and consumptive uses. Stresses the need for recreation planning that will balance such conflicts and will maximize inherent benefits of wildlands. Cites current research that will facilitate such planning: ecological studies, carrying capacity research, and human behavior studies.

13. Brown, Perry J. 1977. Information needs for river recreation planning and management. *In* River recreation management and research Symp. Proc., January 24-27, 1977. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 193-201. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Information inputs to making decisions about recreational use of rivers are described. Major recreational decisions and possible inputs to them are identified. A future scenario for recreational use of rivers is given and the needed research on information inputs is identified within the context of the scenario.

14. Bryan, Robert L. 1977. Canoeing use of Huron-Clinton Metropark. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 121-124. North Cent. For. Exp. Stn., St. Paul, Minnesota.

An urban regional Metropark system (Detroit area) continues to encourage use by canoeists of the Huron and Clinton Rivers. Unrestricted canoeing use has been encouraged by river inventory, maps, clean-up, and canoe rental concessions and facilities. Author suggests a need for different standards for urban rivers than for wild rivers. Believes these standards should include landscaped urban scenes and manufacturing sites as well as natural scenery. And, canoeing use should be unrestricted to alleviate social pressures of urban residents.

15. Cheffins, William F. 1977. New initiatives in heritage preservation: the agreements for recreation and conservation program of Parks Canada. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 232-235. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Parks, Canada, has created a new Program--Agreements for Recreation and Conservation (ARC) to ensure the preservation of a broad range of human and natural heritage resources and to meet the changing leisure-time needs of Canadians. Describes the ARC Program and its charter to identify, plan, preserve, develop, and manage historic waterways, historic land trails, wild rivers, and heritage areas.

16. Countess, Michael L., Walter L. Criley, and B. R. Allison. 1977. Problems and conflicts associated with river recreation programming and management in the East. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 147-150. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Increased river recreation has resulted in conflicts between landowners and users about project development. The authors suggest that controversies typically are due to different attitudes, values, and philosophies, and the failure of the managing agencies to incorporate such considerations in river programs. Most problems and conflicts are symptoms of an uninformed public.

17. Cowgill, Peter. 1971. Too many people on the Colorado River. Natl. Parks Conserv. Mag. 45(11):10-14.

Cites problems of increasing use on the Colorado River through Grand Canyon National Park, Arizona. Problems resulting from the disposal of waste are most acute. Current park management guidelines seek to control the number of users and to protect the most fragile environments. Two issues remain undecided for this section of the Colorado River: wilderness designation and the use of outboard/inboard motors.

18. Craighead, Frank C., Jr. 1965. Semi-wild rivers--the Upper Snake, a river in transition. Naturalist 16(3):6-17.

Settlements and developments along the Snake River have harnessed large sections of the river for hydroelectric energy. Impoundments and dykes have likewise altered its channel and stream flow. Rivers are dynamic and they often change in subtle ways, such as the type of recreation use and users and the man-made structures along rivers. Scientific, informed approaches are needed to classify, evaluate, and manage rivers. Outdoor recreation experiences are influenced by both the uniqueness of the water resource and the quality of recreational experiences. Steps to integrate river recreation management into public planning for an entire river basin are suggested.

19. Craighead, John J. 1965. Wild River. Naturalist 16(3):1-5.

Describes the experience of running a wild river and the fragility of the river resource. Suggests a classification system for types of recreation use of rivers. Urges national legislation to preserve wild rivers for the future.

20. Craighead, John J. 1966. Wild Rivers...in a national scenic rivers system. Naturalist 17(2):29-31.

Analyzes the effectiveness of a wild rivers bill proposed in the 1965 U.S. Senate. Notes lack of river classification system, specific administrative objectives, and methods for evaluating changes in use patterns and user impacts on rivers. Compares wilderness management legislation with proposed river legislation.

21. Curtis, Eric J. 1977. Some legal aspects of river recreation management in the East. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 8-18. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The theme is the almost incredible multiplicity and the complex interrelation of overlapping governmental controls and private lawsuits affecting rivers and streams in the East. A basic formula or approach to help identify, understand, and distinguish these interwoven legal control mechanisms is presented. Certain basic principles, cases, and authorities are incorporated into fable form based upon Siegfried's Rhine Journey.

22. Eastman, Robert L. 1977. River preservation and recreation programs. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 178-182. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The circumstances that led to the passing of the Wild and Scenic River Act in 1968 are reviewed. Also, the legislation that has been considered and passed with respect to adding rivers to the National Wild and Scenic Rivers System is discussed.

23. Elliott, Robert L. 1977. Commercial river outfitting: its educational role and responsibilities to the future. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 213-219. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Three trends are postulated: (1) a decrease in the rate of demand for commercial outfitting services, (2) an increase in demand for "do-it-yourself" trips, and (3) an increase in governmental regulations. The competition between commercial outfitters and private groups on restricted rivers is explored. Suggests that commercial outfitters can be justified for both their "educational" and "public access" services; the outfitter who so justifies his existance can enjoy a greater freedom from worry over future survival.

24. Ellis, Willis H. 1966. Watercourses-recreational uses for water under prior appropriation law. Nat. Resour. J. 6(2):181-185.

Reviews the 1965 court case, Colorado River Water Conservation District versus Rocky Mountain Power Company, in which the District sought to specify rates of flow necessary for fish life in order to prevent further water diversion by the Company. Colorado Supreme Court denied the District the water rights it claimed based on the decision that the State of Colorado has no legal authority to acquire water rights for fish propagation without making a diversion, such as a retaining pond, from the stream. This decision appears to conflict with a 1937 decision that empowered the District to hold sufficient water from natural streams to preserve fish for the benefit of the recreating public.

25. Fisher, Dorothy L. 1976. Congress debates a river's future: the Missouri River. Environmental Comment, June 1976, p. 4-5. (A publication of the Urban Land Institute)

Briefly describes efforts to designate a 170-mile stretch of the Missouri River in north-central Montana into the National Wild and Scenic Rivers Act. Also summarizes the findings of a study to determine suitability of the River for inclusion in the system.

26. Ford, Charles R. 1975. Effect of new legislation on management of river systems. 40th North Am. Wildl. Nat. Resour. Conf. Trans. 40:273-280.

Several recent laws--the Water Resources Development Act of 1974, the Flood Disaster Protection Act of 1973, the Disaster Relief Act Amendments of 1974, the Housing and Community Development Act of 1974, and the Federal Water Pollution Control Act Amendments of 1972--will have a major impact on river management. These laws give the Federal agencies, that are responsible for water resources planning new and improved authority for managing rivers with multiple purposes with multiple means. A brief summary of the parts of each act relevant to improving the management of river systems in urban areas is given. Opportunities for improving the urban environment, preserving green space and wetlands, and conserving and enhancing wildlife are also summarized.

27. Gunn, Clare A. 1977. Urban rivers as recreation resources. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 19-26. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Cites examples of current recreational developments of urban waterways: San Antonio River Walk, Wichita River Parkway, Trent-Severn-Rideau Waterway (Ontario), and New York State Canal Recreation Development Program. Documents benefits: protection of natural amenities, revitalization of downtown, provision of leisure activity, and increases in jobs, incomes, and taxes generated through commercial enterprises related to development.

28. Haack, Lawrence E. 1975. Rivers of the Hiawatha. Naturalist 26(1):24-27.

Describes recreation opportunities on rivers in the Hiawatha National Forest of the Upper Peninsula of Michigan and gives a brief history of land use. Notes Forest Service multiple use management techniques employed in three use zones of the Forest: general forest, travel influence, and water influence.

29. Hammon, Gordon A., Harold K. Cordell, Lewis W. Moncrief, M. Roger Warren, Richard A. Crysdale, and John Graham. 1974. Capacity of water-based recreation systems part I: the state of the art--a literature review. Water Resour. Res. Inst. Rep. 90, 49 p. North Carolina State Univ., Raleigh, North Carolina.

Examines the problem of identifying the optimal use-level of recreation for a given water body. Recognizes the complex and dynamic concept of carrying capacity and reviews literature that relates to factors influencing capacity. Discusses applicability of Liebig's law of the minimum to carrying capacity. Reviews empirical research related to capacity conceptualization and measurement. Stresses the need for theoretical models for measuring capacity.

30. Hecock, Richard D. 1977. Recreational usage and users of rivers. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 279-284. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Describes trends in the recreational use of rivers by studying participation data and usage information. Identifies patterns of socio-economic and experiential characteristics of users. Evaluates existing data and assesses data needs on river recreation use and users.

31. Herbst, John R., and Edgar L. Michalson, eds. 1969. A wild and scenic rivers symposium. July 25-27, 1969. 49 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Directs the Idaho Water Resources Institute to develop criteria for evaluating proposed rivers for inclusion in the National system. Identifies three major research areas for wild and scenic rivers studies: (1) importance of aesthetics in river evaluation; (2) development of quantitative methods to measure economic benefits and trade-offs gained from wild or scenic river status; and, (3) alternative methods of river evaluation.

32. Huser, Verne. 1977. Industry responds to the explosion in river recreation. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 38-44. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Describes the response of private enterprise to the growing interest in river recreation--(1) increase in the number of outfitters, (2) increase in watercraft and gear production, (3) increase in the literature about the sport, and (4) increase in number of services that are provided the river-using public.

33. Ingram, Helen. 1971. Patterns of politics in water resources development. Nat. Resour. J. 11(1):102-118.

Water policy is currently undergoing a rash of criticism. Water development has a strong impact on society and on plants and wildlife, yet little attempt has been made in water policy to fulfill social or environmental goals--primarily because the pattern of politics in water is politically rational. To effectively alter water policy, the long-held view that water is a *local* resource must be changed to reflect its regional and national importance. This change can be brought about through political leadership and education.

34. Iseri, Kathleen T., and W. B. Langbein. 1974. Large rivers of the United States. USDI Geol. Surv. Circ. 686, 10 p. Washington, D.C.

Presents information on the flow of the 28 largest rivers in the United States based on averages during the periods 1931-1960 and 1941-1970. Rivers are classified with respect to their flows as measured by volume of discharge. River lengths and drainage areas provide a subsidiary classification system. Human activity as well as topography, geology, climate, and vegetation greatly affect streamflows and the character of rivers.

35. Lewis, Darrell E., and Gary G. Marsh. 1977. Problems resulting from the increased recreational use of rivers in the West. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 27-31. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Discusses impacts and conflicts created by increasing recreational use of rivers in the western United States. Problems addressed include environmental, social, and administrative interrelations on rivers.

36. Lime, David W. 1975. Backcountry river recreation: problems and research opportunities. Naturalist 26(1):2-6, 16-17.

Identifies increasing use of backcountry rivers and the associated social and environmental problems. Urges sociological research on three topics: (1) how patterns of river use and characteristics of users vary within and between rivers; (2) how current and potential users define a high-quality river recreation experience; and (3) kinds of management techniques needed to increase user enjoyment and decrease resource damage.

37. Lime, David W. 1977. Research for river recreation planning and management. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 202-209. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Three research problem-areas emphasizing social or people problems on rivers are described: (1) how patterns of river recreation use and characteristics of users vary on individual rivers, between different rivers, and with time; (2) how current and potential users define quality river recreation experiences; and (3) how patterns of river recreation use can be modified.

38. Litton, R. Burton, Jr., Robert J. Tetlow, Jens Sorensen, and Russell A. Beatty. 1974. Water and landscape: an aesthetic overview of the role of water in the landscape. 314 p. Water Inf. Cent. Inc., Port Washington, New York.

Discusses the aesthetic role of water on landscape. Proposes a visual classification system for fresh water resources based on landscape, setting, and waterscape. Cites criteria for natural and man-made landscape evaluation. Recommends intra-agency adoption of aesthetic evaluation policies for water so that water-oriented landscapes may be defined and evaluated using aesthetic criteria as major tools. Encourages research that incorporates aesthetic evaluation with benefit cost analysis.

39. Mann, R. 1973. Rivers in the city. 256 p. Praeger Publishers, New York, New York.

Discusses historical, economic, sociological, and aesthetic problems of urban river management and the important aspects of progress in the conservation of river landscapes. Tells how 15 major urban communities have utilized their river landscapes to provide recreational facilities.

40. McCool, Stephen F., L. E. Royer, J. J. Kennedy, and J. D. Hunt. 1974. Recreational use and management problems on Utah's wild rivers. Utah Acad. Sci. Arts Lett. Proc. 51(1):109-115. Utah State Univ., Logan, Utah.

Discusses management problems on wild rivers in the Intermountain West: increased visitor use on flora and fauna native to riverine environments; human waste disposal; motivations of visitors; and opportunities for visitor solitude. Suggests that a carrying capacity-based recreation management system could solve these problems.

41. Michalson, Edgar L. 1975. Part C: wild and scenic rivers. *In* Regional problem analysis in the Pacific Northwest. p. 87-122. Wash. State Univ., Pullman, Washington.

Stresses the need for clarifying problems faced by multiple-agency management of rivers. Suggests that universities take an active role in river research and identifies four general areas needing investigation: (1) environmental problems; (2) carrying capacity (the establishment of limits, management, and the results of management); (3) commercial and non-commercial uses and demands; and (4) jurisdictional arrangement (functional, geographical, agency).

42. Moncrief, Lewis, and Jan Canup. 1974. Forgotten rivers. Parks and Recreation 9(10): 30-33, 68, 70, 72, 74.

The authors argue that the potential of urban rivers for recreational purposes has not been fully realized. Cites the importance of public opinion in urban river reclamation. Urges development of riparian corridors to take advantage of rejuvenated waters. Discusses efforts in Delaware and Texas to implement greenways along urban rivers.

43. Montana Dep. of Fish and Game. 1976. Montana Outdoors 8(2):1-45.

Special issue of the "Montana Outdoors" magazine that emphasizes the Yellowstone River. Articles feature: the role the River has played culturally for the past 200 years; public opinion on future water use; water requirements for industry, fish, wildlife, and recreation; and nine Yellowstone Basin research projects that document the effects of increased water withdrawals on recreation, fish, and wildlife.

44. Nash, Roderick. 1977. River recreation: history and future. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 2-7. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The recent rise of interest in river recreation must be seen against a background of fear of wild rivers as part of the uncontrolled wilderness. Revolutions in ideas, equipment, and technique paved the way for the transformation of river running from a high-risk expedition to family fun. Suggests the future will see increasing competition for the recreational potential of rivers, particularly for float trips.

45. Outdoor Recreation Resources Review Commission. 1962. Sport fishing--today and tomorrow. ORRRC Study Rep. 7, 130 p. Gov. Print. Off., Washington, D.C.

Presents an appraisal of fishing as a form of recreation in the United States and includes a State-by-State survey of the problems of supply, status of fishing waters, and management policies and responsibilities. Covers present and future supply of both warm- and cold-water fish and projects the future of sport fishing by regions.

46. Outdoor Recreation Resources Review Commission. 1962. Water for recreation-values and opportunities. ORRRC Study Rep. 10, 130 p. USDI Geol. Surv., Washington, D.C.

Analyzes future economic demand for water-based recreation in the United States. States that recreationists and industry should compete equally for use of water. Relates factors of water quality and access problems to recreational use of water resources.

47. Painter, Bill. 1976. Understanding the Wild and Scenic Rivers Act. Environmental Comment, June 1976. p. 2-4. Urban Land Institute.

Briefly describes provisions in the National Wild and Scenic Rivers Act of 1968 to protect free-flowing rivers. Notes that the primary aim of the National Wild and Scenic Rivers System is to maintain the status quo along designated rivers.

48. Parry, B. Thomas, and Richard B. Norgaard. 1975. Wasting a river. Environmentalist 17(1):17-20, 25-27.

Criticizes the objectivity of the economic assessment made for the New Melones Dam on the Stanislaus River in California. Gives a brief legal history of the dam controversy. Compares and analyzes Army Corps of Engineers benefit cost estimates with authors' own estimates. Notes lack of quantification of adverse environmental impacts in Corps' analysis and concludes Corps' overestimated benefits and underestimated costs of the project.

49. Peters, Clay E. 1975. A national systems of wild and scenic rivers. Naturalist 26(1):28-31.

Briefly traces the history of the National Wild and Scenic Rivers Act of 1968: rationale for such a river system, processes that add new rivers to the federal system, types of river classification possible (wild, scenic, or recreational), and various management efforts to preserve rivers (zoning, conservation, scenic easements, etc.).

50. Pfister, Robert E. 1975. Protection of free flowing rivers. *In* Water Resources Policy Issues--1975. p. 63-72. Water Resour. Res. Inst., Oregon State Univ., Corvallis, Oregon.

Examines the federal legislative mandate to protect free-flowing rivers and notes challenges to be faced in implementing the policy. Identifies research needs for wild and scenic rivers such as the attitudes of public agency personnel, the impacts of use controls on river users experiences, and the methods to assess intangible benefits of river experiences.

51. Priesnitz, Michael. 1975. The rivers that run on borrowed time. Naturalist 26(1):7-12.

Reviews State of Minnesota river management and planning procedures, including the 1973 Minnesota Wild and Scenic Rivers Act that was aimed at preserving rivers for recreation. Discusses the characteristics and potentials of the Kettle and Mississippi Rivers as possible additions to the State's wild and scenic rivers system--both rivers are close to the St. Paul-Minneapolis metro area and are under pressure to be developed.

52. River Conservation Fund. 1977. Flowing free: a citizen's guide for protecting wild and scenic rivers. 76 p. River Conserv. Fund, Washington, D.C.

Approaches that may be useful in river preservation are presented. The National Wild and Scenic Rivers Act is discussed. The designation process is explained, classification criterion and objectives are presented, and the present status of the System is detailed. State Wild and Scenic Rivers programs are briefly reviewed and a list of State contacts is provided. Examples of local and private preservation efforts are presented as are processes that may be useful in mobilizing the grassroots support needed in a preservation effort.

53. Royer, Lawrence E., Wm. H. Becker, and Richard Schreyer, eds. 1977. Managing Colorado River whitewater--the carrying capacity strategy. Inst. for the Study of Outdoor Recreation and Tourism, Dep. For. and Outdoor Recreation, Utah State Univ., Logan, Utah.

Includes papers by managers and researchers on the issue of carrying capacity of whitewater rivers in the canyon country of Utah. Includes articles on the concept and meaning of protected wildlands, the physical resource and social determinants of whitewater recreation, and social inputs to carrying capacity decisions.

54. Schreyer, Richard. 1976. Behavioral research on whitewater rivers. Utah Tourism and Recreation Rev. 5(1):1-5.

Discusses the development of a behavioral information data-bank to aid recreation managers who are responsible for whitewater rivers. Behavioral information needed about users is: (1) who are they, (2) where do they come from (mentally and geographically), and (3) what do they want? This information would: (1) identify the kinds of experiences users want, (2) allow managers to receive direct feedback on special actions, and (3) help managers "to see" the people using the resource instead of just using "visitor days" and "camper nights" to describe them.

55. Simmons, Robert M. 1977. Legal aspects of river recreation management in the West. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 32-37. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Analyzes the levels of law the river manager should be familiar with; emphasis is on the recent Federal statutes affecting the use of the Nation's waterways. Also analyzes the effects of determining: (1) the navigability of a waterway, (2) the importance of the reservation doctrine, and (3) the effect of existing and future appropriations on river recreation management.

56. Sumner, David. 1975. Will the Dolores live up to its name? Sierra Club Bull. 60(7):4-5.

Chronicles the gradual deterioration of the Dolores River in southwestern Colorado. Notes diversity of ecological realms along the river and describes a river trip from Cahone and Bedrock to the Colorado River in Utah. Urges preservation of the river in the National Wild and Scenic Rivers System.

57. Sumner, David. 1976. Wild rivers, flowing free. Nat. Wildl. 14(4):20-27.

Documents the problems involved in preserving six of the rivers that are either included in the National Wild and Scenic Rivers System or are being studied to be included. Discusses controversial issues and problems involved in preserving the areas yet managing them for various types of activities.

58. Tarlock, Dan A. 1967. Preservation of scenic rivers. Kentucky Law J. 55(4):745-798.

Suggests that preserving free-flowing water is a public value that should be considered in water resources planning decisions. Offers methods of incorporating these values into the decision-making process. States that at present, preservation is a value secondary to development and that existing laws favor short term uses of water (power generation, flood control, and irrigation) over long term uses. Maintains that technology will continue to increase leisure time and that preserving some of the remaining unharnessed stretches of rivers will help sustain important recreational opportunities.

59. Thompson, Glenn. 1976. Lucky river: the Little Miami. Environmental Comment, June 1976. p. 13-16. Urban Land Inst.

Briefly discusses the historical significance of the Little Miami River in southwest Ohio. Describes the processes that a nonprofit organization, Little Miami, Inc., undertook to rally support for protection of the River. Provides examples of accomplishments by the organization, individuals, and public agencies to protect the River.

60. Tippy, Roger. 1968. Preservation values in river basin planning. Nat. Resour. J. 8(2):259-278.

Three values are identified as reasons for preserving streams: recreation, fish, and a set of intangibles such as wilderness, natural beauty, and historic and scientific values. Major development values of rivers are: agricultural and domestic consumption, flood control, navigation, hydroelectric power, dams, and soil conservation. Conflicts between preservationists and developers often occur thereby establishing a need for comprehensive river basin planning. Ideally planners should either present decision-makers with a choice of alternatives for a given river or a single answer that does not dissatisfy one interest group more than another. The comprehensive planning program for the Upper Missouri River basin could guide other river basin planning efforts.

61. Turner, Robert C. 1974. The preservation of rivers as wild and scenic. *In* Environmental planning: law of land and resources. p. 8.1-8.16. Arnold W. Reitze, Jr., ed. North Am. Interntl., Washington, D.C.

Presents a brief history of the Wild and Scenic Rivers Act. Comments on the procedures followed to preserve rivers under the Act and the management guidelines followed to protect both the river and its corridor. Riverways that are protected by other Federal legislation, such as the Jacks Fork and Current Rivers in the Missouri Ozarks and the Buffalo River in Arkansas, are also mentioned. The effectiveness of measures used to protect these rivers are briefly compared with measures used to protect rivers under the Wild and Scenic Rivers Act. State scenic river programs as they relate to eligibility requirements for Federal land and water conservation funds are discussed also.

62. U.S. Department of Interior, Bureau of Outdoor Recreation. 1970. National symposium on wild, scenic and recreational waterways: proceedings. September 10-12, 1970. 209 p. St. Paul, Minnesota.

A collection of papers that reviews the Wild and Scenic Rivers Act of 1968, answers the most frequently asked questions regarding the Wild and Scenic Rivers System, discusses complementary State river programs, and outlines methods for implementing the various rivers programs.

63. U.S. Department of Interior, Bureau of Outdoor Recreation. 1976. Northeast regional states scenic rivers planning workshop. Summary of Proceedings. May 25-27, 1976. Rexford, Pennsylvania. 117 p.

Summarizes the discussions of State and Federal resource administrators responsible for river planning and management in the Northeast. Important topics discussed were: (1) the river study process; (2) the river designation process; (3) the development of a river management plan and implementation process; and (4) status of the National and Wild Scenic River System

64. U.S. Department of Interior, Bureau of Outdoor Recreation. 1977. Outdoor recreation action: wild and scenic river. 43:1-48.

Discusses America's wild and scenic rivers and efforts to protect and preserve them. Articles feature: a status report on river preservation and recreation programs; a summarization of various State stream protection programs (key contacts in State government charged with river protection are listed); a review of Federal Wild and Scenic River protection efforts; and a summary of the River Recreation Management and Research Symposium held in Minneapolis in January 1977.

65. U.S. Department of Interior, Fish and Wildlife Service. 1975. Proceedings of the National wetland classification and inventory workshop. July 20-23, 1975. College Park, Maryland. 248 p. & addendum. Washington, D.C.

Contains overviews of current wetland classifications and inventories in the United States and Canada by various public agencies (both State and Federal) and private organizations. Workshop session discussions are provided. Appended section incorporates many suggestions that emanated from the workshops.

66. U.S. Senate Select Committee on National Water Resources. 1960. Water resources activities in the United States; water recreation needs in the United States, 1960-2000. Comm. Print 17, 86th Congr. 2d. Sess. Gov. Print. Off., Washington, D.C.

Covers such topics as the rapidly increasing use of water-based areas, problems of intensive use and crowding, planning for additional areas, public water supply legislation, and inadequate criteria for estimating future water-based recreation needs. Contains 17 recommendations by the National Park Service regarding Federal objectives for water-related recreation areas. An Appendix contains recommendations for general policy by the Committee.

67. Utter, Jack G., and John D. Schultz. 1976. A handbook on the Wild and Scenic Rivers Act. 44 p. Sch. For., Univ. Montana, Missoula, Montana.

Booklet is divided into four parts: (1) text of the Act, (2) section-by-section review of the Act, (3) texts of legislation enacted by Congress since the Act passed that pertain directly to the Act, and (4) Federal regulations and the Wild and Scenic Rivers Act.

3
INVENTORY AND CLASSIFICATION METHODS

(Also see reference numbers 31, 34, 38, 65)

68. Arighi, Scott, and Margaret S. Arighi. 1974. Wildwater touring. 334 p. MacMillan Co., Inc., New York, New York.

Contains a section on a method for classifying rivers as to the difficulty the river user experiences while attempting to navigate the river. Difficulty ratings are also defined by the type of water craft used to float a river.

69. Aukerman, Robert, and George Chesley. 1971. Classifying water bodies: feasibility and recommendations for classifying water. 123 p. Final Report, Dep. Recreation Resour. Colorado State Univ., Ft. Collins, Colorado.

Determines the feasibility of classifying water bodies and segments of water bodies by potential use. Identifies criteria for a water classification system and evaluates existing natural resource classification systems. Finds that satisfactory classification by potential optimum use requires a comprehensive planning process that identifies conflicts and is basically a decision-making system.

70. Bauman, Eric Hans. 1976. A method for assessing river recreation potential. M.A. thesis. Dep. Geogr., Michigan State Univ., East Lansing, Michigan. 188 p.

Develops an objective method to evaluate the recreational potential of riparian corridors and to inventory existing river characteristics. Sixty-seven variables in eight categories were evaluated along river segments of the Pine, Manistee, and Looking Glass Rivers in Michigan. Each variable was ranked for 16 recreation activities. A literature review of techniques for assessing recreation values is included.

71. Borden, Yates F., Brian J. Turner, and Charles H. Strauss. 1977. Colorado River campsite inventory. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 226-231. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Shoreline beaches along the Colorado River in the Grand Canyon are regularly used by river-running parties as overnight campsites. The availability of campsites in river sections where they are scarce, small, or both, limits the number and size of parties that can be permitted without risking unacceptable environmental degradation. Therefore, a comprehensive inventory of usable campsites was made and it revealed that 345 campsites are available for overnight camping by river-running parties.

72. Calvin, James S., John A. Dearinger, and Mary Ellen Curtis. 1972. An attempt at assessing preferences for natural landscape. Environ. Behav. 4(4):447-470.

Two samples of college students were asked to judge 15 different views of natural scenery on each of 21 different scales. Results suggest that there may be two major dimensions people use in subjective assessments of natural scenery: natural scenic beauty and natural force-natural tranquility. Scenic beauty moves along scale dimensions from beautiful to ugly. Natural force scenes are judged as being turbulent, loud, rugged, and complex; and natural tranquility scenes are tranquil, hushed, delicate, and simple.

73. Carlson, J. E., D. L. Grant, E. L. Michalson, J. H. Mulligan, and J. K. Van Leuven. 1976. Developing criteria to classify wild and scenic rivers. Res. Tech. Completion Rep. 117 p. Idaho Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Presents a multidisciplinary effort to develop river classification alternatives. Physical, economic, and community density factors were each given a numerical value on six natural river stretches along the Priest River and Priest Lake in Idaho. The values were then used to compare the suitability of each of the stretches with the 3 classification criteria (wild, scenic, recreational) specified under the National Wild and Scenic Rivers Act.

74. Cherem, Gabriel J., and David E. Traweek. 1977. Visitor employed photography: a tool for interpretive planning on river environments. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 236-244. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The methodology of visitor employed photography (VEP) is explained as a device to inventory public perception of natural environments. A VEP study on the Huron River in Michigan is summarized and the use of VEP findings in the development of interpretive services and programs for river environments is discussed.

75. Chubb, Michael. 1977. River recreation potential assessment: a progress report. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 83-90. North Cent. For. Exp. Stn., St. Paul, Minnesota.

In the past most river recreation was managed from the viewpoint of rectangular land areas rather than complete river systems. Managing from a river-oriented viewpoint gained momentum with the passage of the Federal Wild and Scenic Rivers Act, but no widely adopted method of assessing river recreation potential has yet been developed. Several approaches to potential assessment are summarized. The RIVERS Method involves assessing 67 variables for each mile of river and evaluating the potential for 16 recreational activities.

76. Chubb, Michael, and Eric H. Bauman. 1977. Assessing the recreation potential of rivers. J. Soil and Water Conserv. 32(2):97-102.

Although many ways of assessing river recreation potential have been suggested, no universally applicable method has been devised. The RIVERS Method, currently under development for the USDA Forest Service, attempts to evaluate and compare the potential of all types of rivers for recreation activities.

77. Coomber, Nicholas H., and Asit K. Biswas. 1973. Evaluation of environmental intangibles. 74 p. Genera Press, Bronxville, New York.

Reviews the state of the art of evaluating intangible benefits and costs associated with the use of the environment. Cites Leopold's inventory technique to assess environmental quality of rivers as being more illustrative rather than analytic. Distinguishes between two types of classification techniques: monetary evaluations of environmental intangibles and nonmonetary evaluations of the physical environment.

78. Craighead, Frank C., Jr., and John J. Craighead. 1965. River systems-recreational classification, inventory and evaluation. Naturalist 16(3):33-43. (Reprinted from Naturalist 13(2), 1962.)

Proposes a method to inventory and evaluate river recreation resources based on size, condition, and recreation use of the rivers. Delineates four classes of rivers: wild, semiwild, semiharnessed/developed, and harnessed/developed.

79. Dearinger, John A. 1968. Aesthetic and recreational potential of small naturalistic streams near urban areas. Res. Rep. 13, 260 p. Water Resour. Res. Inst., Univ. Kentucky, Lexington, Kentucky.

A method was developed to evaluate aesthetic and recreational potential of streams and watersheds based on previous work by the U.S. Soil Conservation Service and on the principles of terrain analysis, land use planning, and outdoor recreation economics. Evaluations of stream recreation potential for activities such as camping, fishing, and hiking were made. Concludes that aesthetic and recreational values can be identified, inventoried, and used to evaluate a watershed's development potential; and that accurate estimates of participation demand, acreage requirements for various activities, and benefits gained (by both users and developers) from recreational developments can be projected.

80. Dearinger, John A., and George M. Woolwine. 1971. Measuring the intangible values of natural streams: Part I--applications of the uniqueness concept. Res. Rep. 40, 86 p. Water Resour. Res. Inst., Univ. Kentucky, Lexington, Kentucky.

Applies Leopold's river inventory system for uniqueness to 58 natural streams in Kentucky. Concludes that the concept is useful to evaluate the uniqueness of a group of streams. Encourages further integration of the uniqueness concept into benefit-cost analysis and makes specific recommendations for further research.

81. Dearinger, John A., George M. Woolwine, Charles R. Scroggin, D. Daland, and J. Calvin. 1973. Measuring the intangible values of natural streams: Part II--preference studies and completion report. Water Resour. Res. Inst. Res. Pap. 66, 206 p. Univ. Kentucky, Lexington, Kentucky.

A method that utilizes color slides and a semantic differential rating scheme was developed to measure people's preferences for natural landscapes. Concludes that: scenes with running water are preferred over scenes with still or no water; stark beauty of a desert, lava flow, or winter pasture is not perceived as beauty by most people; some types of visual pollution (i.e., billboards) are not recognized as such by many people; occupation and lifestyle have more of an effect on an individual's concept of natural beauty than does age or sex; and people generally agree on what is very beautiful or very ugly but not on the in-between.

82. deBettencourt, James, and George L. Peterson. 1977. Standards of environmental quality for recreational evaluation of rivers. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 245-255. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Explores the possibility of developing criteria and standards based upon the individual and groups threshold functions by which alternative river recreation sites are accepted or rejected. Explains experimental procedures used to develop the threshold functions. Presents illustrative results of pilot studies. Suggests applications and needs for further research.

83. Dyer, A. Allen. 1969. Recreation site selection: a conceptual approach. 23 p. Inst. Study Outdoor Recreation Tourism, Utah State Univ., Logan, Utah.

Proposes formulating a computerized recreation land model that would incorporate consumer preferences in selecting recreation sites for development. The data base for the model would rest on physical characteristics of the proposed site. Two types of data are needed to operate the model: an assessment of environmental characteristics required for several activities and an inventory of land characteristics pertinent to site quality. Three groups of recreational activities are identified: water based, land based, and winter.

84. Frissell, Sidney S., Jr., and Donald P. Duncan. 1965. Campsite preference and deterioration. J. For. 63(4):256-260.

Describes research undertaken in the Quetico-Superior canoe country of Minnesota and Ontario to determine (a) preferences of canoeists for campsites, (b) character and degree of campsite deterioration, and (c) feasibility of developing prediction equations for campsite durability. Regression analyses were used to develop an equation for the prediction of the durability of alternative sites that might be developed in the future to disperse camping use.

85. Gilchrist, Martin C. 1971. Strategies for preserving scenic rivers: the Maryland experience. Landscape Archit. 62(1):35-42.

Describes procedures to evaluate Maryland rivers for potential scenic river protection. Criteria for protection include physical, biological, and human conditions along a river and its corridor.

86. Gunn, Clare A., John W. Hanna, Arthur J. Parenzin, and Fred M. Blumberg. 1974. Development of criteria for evaluating urban river settings for tourism-recreation use. Texas Water Resour. Inst., Tech. Rep. 56, 98 p. Texas A&M Univ., College Station, Texas.

Develops criteria to enable cities to evaluate the potential for business-recreation development along downtown waterfront locations. Suggests that development will stimulate revival of downtown areas and will allow diverse interests to coordinate leadership on resource management. Examples of waterfront redevelopment in various American cities are presented.

87. Hamill, Louis. 1974. Statistical test of Leopold's system for quantifying aesthetic factors among rivers. Water Resour. Res. 10(3):395-401.

Criticizes Leopold's inventory method to quantify the aesthetic factors of rivers. Statistical tests show small correlation between uniqueness ratios in Leopold's method and other rating methods. Anomalies were also found in graphic derivation of Leopold's technique. Suggests that a number-ranking system would be a more efficient evaluation tool.

88. Hamill, Louis. 1975. Analysis of Leopold's quantitative comparisons of landscape aesthetics. J. Leisure Res. 7(1):16-28.

In 1969 Luna B. Leopold published a system for quantitatively comparing landscape aesthetics. This system had several features such as the uniqueness ratios and distinctive graphical procedures for deriving river and valley character. An examination of Leopold's checklist for landscape factors reveals that the system for rating each factor is inconsistent. Inconsistency is justified as not introducing bias and personal preferences into the analysis. The use of uniqueness ratios appears to have been required in order to accommodate the inconsistent scaling of factors to numerical analysis. The addition of uniqueness ratios produces difficulties of comprehension and interpretation. The graphical procedures use a small amount of information and complex graphical techniques to produce scales of river and valley character. Analysis of the system suggested that consistent rating of environmental factors and the addition of factor scalings might have produced comparable results more effectively.

89. Hamill, Louis. 1977. Methods used for evaluating recreational rivers in Canada. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 273-278. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Reviews techniques for describing and evaluating recreational rivers in Canada. Considers methods developed and/or tested in Canada and methods developed elsewhere that have been applied in Canada.

90. Hammon, Gordon A., Harold K. Cordell, Lewis W. Moncrief, M. Roger Warren, Richard A. Crysdale, and John Graham. 1974. Capacity of water-based recreation systems Part II: a systems approach to capacity analysis. Water Resour. Res. Inst. Rep. 90, 46 p. North Carolina State Univ., Raleigh, North Carolina.

Develops methods, models, and guidelines useful to managers who are interested in measuring or predicting the recreational output of lakes. Presents several explanatory models representing individual and group behavior of pleasure boaters.

91. Herbst, John R. 1972. Report of forest subprojects: a methodology study to develop evaluation criteria for wild and scenic rivers. 52 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Presents a timber inventory of the Salmon River basin to determine the impact that the wild and scenic river classification would have on timber harvesting activities in the area. Notes that timber-market boundaries rather than geographic boundaries are more relevant when examining and comparing the effects river classification would have on the timber industry. Concludes designation in the National Wild and Scenic River System would have little effect on timber harvesting activities.

92. Herbst, John R. 1973. Report of range subproject: a methodology study to develop evaluation criteria for wild and scenic rivers. Scenic Rivers Study Rep. 3, 49 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Discusses the importance of grazing in the Salmon River basin and the effects Federal wild and scenic river designation might have. Develops an evaluation method to determine the impact of designation on grazing and concludes that little conflict would exist.

93. Herrington, Roscoe B., and S. Ross Tocher. 1967. Aerial photo techniques for a recreation inventory of mountain lakes and streams. USDA For. Serv. Res. Pap. INT-37, 21 p. Intermt. For. Range Exp. Stn., Ogden, Utah.

Describes the results of aerial photo techniques tested on the north slope of the Uinta Mountains in Utah to measure physical characteristics of mountain lakes and streams. Compares the accuracy of photo determination with field measurements of lake depth. Describes procedures for all-photo measurements in the inventory. Concludes that a substantial amount of descriptive data can be obtained from aerial photos.

94. Hooper, R. A. 1977. Assessing the recreational potential of waterways: a description and evaluation of selected systems. Res. Pap. 77-1, 51 p. Navigable Mt. Rivers Study, Nat. Hist. Res. Div., Parks Canada, Western Region, Calgary, Alberta.

Describes and evaluates systems suitable for measuring the recreational potential of waterways--particularly canoeing, kayaking, rafting, and activities associated with these forms of recreational boating. These systems were tested on the Gammon River in Manitoba in 1974.

95. Hooper, R. A. 1977. A guide to the nature of mountain rivers and whitewater. Res. Pap. 77-2, 31 p. Navigable Mt. Rivers Study, Nat. Hist. Res. Div., Parks Canada, Western Region, Calgary, Alberta.

Acquaints the reader with some aspects of mountain river hydrology, channel morphology, and the hydraulic principles affecting whitewater features. Also, briefly discusses a system developed to rate the paddling difficulty of whitewater.

96. Hooper, R. A. 1977. A system to inventory and evaluate mountain rivers for canoeing and kayaking: a basis for the determination of recreational potential. Res. Pap. 77-3, 70 p. Navigable Mt. Rivers Study, Nat. Hist. Res. Div., Parks Canada, Western Region, Calgary, Alberta.

Outlines the steps taken to determine the recreational potential of several Canadian mountain rivers. First, a detailed inventory and evaluation of the rivers was completed. Then, management and operational guidelines pertaining to canoeing, kayaking, and rafting were developed. General management concerns included: requiring registration systems, establishing public safety programs, establishing recreational carrying capacity limits and procedures, establishing restrictions and guidelines for on-shore activities related to boating, and assessing public information requirements. Also river users should be surveyed to help develop the management plans. A questionnaire used for this purpose on Canadian rivers is presented.

97. Juurand, Priidu. 1972. Summary report on the wild rivers survey, Yukon Territory, 1971. 25 p. Can. Dep. Indian Aff. North Dev., Natl. Hist. Parks Branch, Plann. Dev., Ottawa, Canada.

Summarizes a wild rivers survey conducted in the Yukon Territory during the summer of 1971. Information was collected to test methods (such as Leopold's uniqueness ratio) for ranking rivers for inclusion in a system of wild rivers. Subjective analysis of each study river was conducted and the results are summarized. Recommends inclusion of the Yukon and Ogilvie-Peel Rivers in a Canadian wild and scenic rivers system.

98. Juurand, Priidu. 1972. Wild rivers survey 1971: quantitative comparison of river landscapes. Spec. Rep. 72-1, 29 p. Can. Dep. Indian Aff. North Dev., Natl. Hist. Parks Branch, Plann. Div., Ottawa, Canada.

Reviews wild river evaluation techniques and selects a modified version of Leopold's inventory method to use in collecting data on Canadian rivers. Recommends that historical, geological, biological, and recreational capability information be added to the inventory technique. Field test concludes Lewes-Yukon and Ogilvie-Peel Rivers as high-priority considerations for Canadian wild and scenic river status.

99. Knudson, Douglas M. 1976. A system for evaluating scenic rivers. Water Resour. Bull. 12(2):281-289.

Describes a system for evaluating rivers for classification in State programs. The system described was developed for Indiana rivers. Rivers must first meet minimum standards for naturalness and suitable adjoining land areas. Then they are rated on bank vegetation, stream course alterations, man-made structures and roads near and across the river, aesthetic quality of the water, and special natural features. Sample rating for the Tippecanoe River is included.

100. Kuska, James J., J. S. Edstrom, and M. H. Smithberg. 1974. St. Croix-Namekagon River Resource Inventory. Agric. Exp. Stn. Misc. Rep. 122-1974, 23 p. Univ. Minnesota, St. Paul, Minnesota.

Describes a method used to categorize resource features for evaluation of recreation site potential along the St. Croix and Namekagon Rivers in Wisconsin and Minnesota. Three environmental factors were studied: (1) regional characteristics (geology, topography, soils, vegetation), (2) river criteria (length, gradient, width, rapids, sinuosity, island) and (3) cultural features (roads, railroads, towns, residences). The optimum location for developing user facilities can be determined by using this method.

101. Kuska, James, and Vince A. Lamarra, Jr. 1973. Use of drainage patterns and densities to evaluate large scale land areas for resource management. J. Environ. Syst. 3(2):85-100.

A 6,800 square mile watershed (St. Croix River, Minnesota-Wisconsin) was studied using the pattern analysis technique. Drainage densities were correlated with soil textures and vegetation and inferences were made about the innate ecological diversity and management potential of the watershed. The information gained from this technique should aid managers in recognizing the diversified nature of a watershed and areas within it that are best suited for road building, logging, recreation development, and wildlife management.

102. Leopold, Luna B. 1962. Rivers. Am. Sci. 50(4):511-537.

Analyzes the hydrologic cycle and the river's role in water transfer. Groups river characteristics into three broad categories: river channel, river valley, and drainage nets. Reviews research conducted on various river characteristics. Lists additional areas needing to be researched: mechanics of sediment transportation, energy dissipation in rivers and its effect on erosion or deposition, and methods of material transport from slopes into river channels.

103. Leopold, Luna B. 1969. Landscape aesthetics. Nat. Hist. 78(8):36-45.

Discusses the development of an inventory method to compare the aesthetic uniqueness of Hell's Canyon of the Snake River in Idaho with 11 other river valleys in Idaho.

104. Leopold, Luna B. 1969. Quantitative comparison of some aesthetic factors among rivers. USDI Geol. Surv. Circ. 620, 16 p. Washington, D.C.

Develops a quantitative inventory and evaluation technique based on the assumption that a unique landscape has more significance than a common one. Defines the physical, biological, and cultural characteristics of 12 Idaho rivers and 4 National Park rivers in terms of 46 variables. A measure of uniqueness is derived by summing the calculated ratios for each variable.

105. Leopold, Luna B., and Maura O'Brien Marchand. 1968. On the quantitative inventory of the river-scape. Water Resour. Res. 4(4):709-717.

Develops a way to quantify the presence or absence of factors that contribute to aesthetic values of a river landscape as expressed by a uniqueness ratio. Discusses inherent difficulties in such research but suggests that the techniques can be a valuable procedure in river-basin planning.

106. Libby, David. 1975. The recreational potential of selected rivers in New Brunswick. 78 p. Plann. Sect., Tech. Serv. Branch Dep. Tourism, Fredericton, New Brunswick.

Uniqueness ratios were calculated for 18 rivers in New Brunswick using Leopold's basic concept. Rivers were ranked on quality, aesthetic appeal and human interest and total attractiveness. User conflicts related to recreation canoeing and associated activities were identified. The river's natural attractiveness, scope of significance, average canoeability, and the apparent likelihood of misuse were considered and each of these factors were rated and summed.

107. Litton, R. Burton, Jr. 1977. River landscape quality and its assessment. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 46-54. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Illustrates the elements of visual assessment of river landscapes: (1) landforms, (2) vegetation patterns, (3) water presence and expression, (4) human use and impacts, and (5) other influences. Discusses how to inventory landscapes at large and small scales of application, and with implications of planning and design policies. Points up problems of evaluating landscape quality using criteria such as aesthetics applied to landscape, professional judgment, and perceptual studies.

108. MacConnell, William P., and G. Peter Stoll. 1968. Use of aerial photographs to evaluate the recreational resources of the Connecticut River in Massachusetts. Holdsworth Nat. Resour. Cent. & Exp. Stn., Coll. Agric. Bull. 578, 65 p. Univ. Massachusetts, Amherst, Massachusetts.

Develops and tests aerial photographic techniques on the Connecticut River to identify and classify river-oriented recreation sites. Analyzes two sets of aerial photos for land uses and development trends. Identifies 102 land use types, and presents a statistical summary of the land (by political unit) for analyzing the recreation potential of the River.

109. MacConnell, William P., and H. Ross Pywell. 1969. Use of aerial photographs to evaluate the recreational resources of the Connecticut River in Connecticut. Coll. Agric. Exp. Stn., Bull. 574, 73 p. Univ. Massachusetts, Amherst, Massachusetts.

Develops and tests aerial photographic techniques for identifying and classifying river-based recreation sites on the Connecticut River. System is used to describe and to note changes in vegetation and land use characteristics.

110. Melhorn, Wilton N., Edward A. Keller, and Richard A. McBane. 1975. Landscape aesthetics numerically defined (LAND system): application to fluvial environments. Tech. Rep. 1, 169 p. Water Resour. Res. Cent., Purdue Univ., Lafayette, Indiana.

Develops a quantitative method for objectively assessing aesthetic values in a fluvial landscape. The LAND system is an extension of Leopold's river inventory scheme. Five evaluative indices are utilized to assess environmental beauty: uniqueness, aesthetic value, scenic beauty, recreation potential, and wildness. Initial testing of the system indicates that participants consistently derive similar numerical values for beauty regardless of their educational background.

111. Michalson, Edgar L. 1974. Aesthetics of wild and scenic rivers--a methodology approach. Scenic Rivers Study Rep. 11, 139 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Study focuses on two tasks: developing a method to evaluate the aesthetic value of wild and scenic rivers and developing demand models for outdoor recreation to estimate how much recreation demand is related to aesthetics. Concludes that quantification of aesthetics is an imperfect art that requires more research.

112. Michalson, Edgar L., and Joel R. Hamilton. 1973. Summary report for a methodology study to develop evaluation criteria for wild and scenic rivers. Scenic River Study Rep. 10, 185 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Develops a method for river evaluation to determine which rivers should be included in the National Wild and Scenic River System. The Salmon River basin in Idaho was selected as a test case for the method. Study concentrated on the entire river basin and the effects wild and scenic river classification would have on basin resources. Two competing river resource uses identified were hydropower and recreation. Attempts were made to estimate trade-offs of hydropower development versus recreation in the Salmon River basin.

113. Michalson, Edgar L., and Joel R. Hamilton. 1975. A methodology for evaluating development-environmental conflicts on wild and scenic rivers. Water Resour. Bull. 11(6):1149-1156.

The Salmon River in Idaho is used as an example in formulating a three-step process for examining environment-development conflicts. The process involves: (1) inventorying resources to determine areas of conflict affecting wild and scenic river status, (2) determining through an evaluation process which resources uses are viable for the river, and (3) comparing various resource uses to determine their economic trade-off values.

114. Morisawa, Marie. 1970. Evaluating riverscapes. *In* Environmental geomorphology. p. 91-106. Donald R. Coates, ed. State Univ. New York, Binghamton, New York.

Discusses a process to rank the intangible values of a riverscape. Reviews research in analyzing aesthetics and in quantitatively evaluating scenic beauty. Relates the pleasurable feelings of the observer in the environment to art criteria (i.e., arrangement of lines, mass, color, and space). Encourages research in methodology to predict user preferences so that riverscapes with outstanding scenic value may be preserved.

115. Morisawa, Marie. 1971. Evaluation of natural river environments. Phase II, Final Rep., 114 p. USDI Water Resour. Res. State Univ. New York, Binghamton, New York.

Methods of evaluating various aspects (physical, cultural, hydrologic, and aesthetic) of watersheds were tested on six rivers representing a variety of natural environments. Criteria to inventory and classify natural environments as well as methods to evaluate cultural (scenic and historic) values were identified. Application of methodology to watershed management and planning is stressed.

116. Morisawa, Marie, and Martin Murie. 1969. Evaluation of natural river environments. Final Rep., 143 p. USDI Water Resour. Res., Antioch College, Yellow Springs, Ohio.

Methods were devised to objectively identify and assess values (biological, geological, aesthetic, and recreational) of rivers in their natural, free-flowing state, and to compare these values with those of more developed rivers. Field data on fauna, flora, geology, hydrology, history, and aesthetics were collected for the Green River, Wyoming, and the Little Miami River, Ohio, to supply an inventory of features along each river. Although both rivers were considered natural and free-flowing, classification schemes and ratings for each value applied to these two rivers show sharp distinctions between them.

117. Morris, James A. 1976. Instream flow evaluation for outdoor recreation. *In* Instream flow needs Spec. Conf. and Symp. Proc., Vol. II, May 3-6, 1976, Boise, Idaho, p. 352-358. Am. Fish. Soc., Bethesda, Maryland.

Recreation is accepted as a legal, competing use for water. Planning guidelines accent the need for ways to evaluate trade-offs among all water uses. A method to subjectively evaluate the effects of different instream flows on river-related recreation activities is proposed. This method should be adaptable to current water resource planning guidelines and be simple to apply.

118. Natural Historical Parks Branch, Planning Division. 1973. Summary report wild rivers survey 1972. Spec. Rep. 73-3, 65 p. Can. Dep. Indian Aff. North Dev., Ottawa, Canada.

Summarizes a 1972 inventory of wild rivers in Canada. Study rivers were chosen for their potential national park-natural region representation, association with historic routes, or logistics. Results are presented by region: western mountain area, barrenlands area in the northwest, Canadian shield (central), Canadian shield (eastern), and Appalachians area in Newfoundland. Evaluation of river sections is based on river location, water and channel characteristics, valley characteristics, historical/cultural features, scenic quality, and recreation quality.

119. Niemann, Bernard J., Jr., Xavier A. Bonilla, and S. Richard Bruno. 1975. Rural landscape assessment: a comparative evaluation of high platform remote sensors. 243 p. Dep. Landscape Arch./Environ. Awareness Cent., Sch. Nat. Resour., Coll. Agric. and Life Sci., Univ. Wisconsin, Madison, Wisconsin.

The St. Croix and Namekagon River system and surrounding landscape in Wisconsin was used as the test site to compare and evaluate the usefulness of high platform remote sensing with conventional resource assessment methods. Results indicate that high altitude color infrared photography is comparable with conventional assessment methods. Good results were obtained through remote sensing.

120. Nighswonger, James J. 1970. A methodology for inventorying and evaluating the scenic quality and related recreational value of Kansas streams. Kansas Plann. Dev. Rep. 32, 119 p. Kansas Dep. Econ. Dev. Plann. Div., Topeka, Kansas.

Develops a technique for inventorying, evaluating, and analyzing Kansas' streams for visual quality and recreational potential. Concludes that the most significant streams, in terms of visual quality, are located in the eastern one-third of Kansas where water, topography, and vegetation combine for visual diversity.

121. Rickert, David A., and Walter G. Hines. 1975. A practical framework for river-quality assessment. USDI Geol. Surv. Circ. 715-A, 17 p. Washington, D.C.

Presents a seven-step framework for comprehensively assessing river quality: (1) determine existing and potential river quality, (2) analyze river hydrology, (3) select assessment methods, (4) collect data, (5) analyze data, (6) predict impacts on future planning, and (7) communicate results to clients. The Willamette River Basin in Oregon was used as a case study.

122. Sonnen, Michael B., Larry C. Davis, William R. Norton, and Gerald T. Orlob. 1970. Wild Rivers: methods for evaluation. Final Completion Rep., 116 p. Water Resour. Eng. Inc., Walnut Creek, California.

Develops two methods of evaluating wild and scenic river potential to include intangible, nonmonetary benefit values. Each method was tested on two adjacent river basins in Washington--the Upper Skagit (a currently developed basin) and the Sauk-Suittle (a wild river basin). The results of each test indicated that the Sauk-Suittle River should be left wild and the Skagit River could be more fully developed.

123. Stalnaker, C. B., and J. L. Arnette (ed.). 1976. Methodologies for the determination of stream resource flow requirements: an assessment. 199 p. USDI Fish and Wildl. Serv., Off. Biol. Serv., Lakewood, Colorado.

Examines techniques and methods used to assess instream flow requirements for fish and other aquatic life, wildlife, recreation activities, and aesthetic values. Discusses the measurement of recreation activities and the assessment of those social attitudes that affect demand or potential demand for stream-associated recreation resources. Analyzes the aesthetics of flowing streams and adjacent landscapes. Measuring aesthetics is discussed with emphasis upon viewer evaluation and environmental qualities.

124. Taylor, Gordon D. 1965. Approach to the inventory of recreational lands. Can. Geogr. 9(2):84-91.

Proposes a classification system of recreational lands based on characteristics that different land areas have in common and on the intensity of recreational use of various lands. Criteria used in classification include: attractibility, vegetative cover, slope, size, and availability of drinking water.

125. Taylor, Gordon D., and Clarke W. Thompson. 1966. Proposed methodology for an inventory and classification of land for recreational use. For. Chron. 42(2):153-159.

Presents a method to inventory and rank landscapes for recreational use. Utilizes four criteria to evaluate them: water, cover, slope, and relief. Delineates a four-fold process to both itemize and scale landscape types. The recreational potential of sites is based on the presence or absence of limiting factors that affect their development for recreational uses.

126. Terry, Claude E. 1977. A filter system for determining river suitability for National Wild and Scenic River status. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 372-379. North Cent. For. Exp. Stn., St. Paul, Minnesota.

A system of filter matrices is described and its application to rivers in the Appalachian plateau evaluated. Based upon subsequent aerial observation and input from users, the system appears applicable in identifying streams that could logically be considered for inclusion in the National Wild and Scenic River System.

4
ECONOMIC EVALUATIONS

(Also see reference numbers 46, 111, 112, 113, 117)

127. Bianchi, Dennis H. 1969. The economic value of streams for fishing. Res. Rep. 25, 119 p. Water Resour. Res. Inst., Univ. Kentucky, Lexington, Kentucky.

Presents the results of an interview study of Kentucky stream fishermen. Notes the decline of natural stream fisheries. Develops a method to estimate the economic and recreational value of streams to fishermen. When estimating net benefits for economic justification, the recreational value of "lost" natural stream fisheries should be deducted from the value gained through reservoir recreation. Concludes that the unit value of a fisherman-day varies as a function of both the geographical location of a stream and its state of naturalness.

128. Blank, Uel, and Sterling H. Stipe. 1971. Economic impact of the Crow Wing Trail, Wadena County, Minnesota. USDA Econ. Res. Serv. 467, 29 p. U.S. Dep. Agric., Agric. Exp. Stn., Univ. Minnesota, St. Paul, Minnesota.

Discusses efforts since 1964 by private groups, individuals, and government sponsored programs in Wadena County to develop the Crow Wing River for canoeing and related recreation activities. Positive economic impacts of development on surrounding communities have been: additional employment; about $50,000 per year of additional income; and, complementary rather than competitive with other recreation facilities in the County.

129. Davis, Robert K. 1963. Recreation planning as an economic problem. Nat. Res. J. 3(2):239-249.

States that perceiving the values to society of different amounts and kinds of recreation areas and facilities is the key to allocating future funding. Also, because no dichotomy between economics and aesthetics exists, economics (especially cost benefit analysis), is a useful tool at all levels of recreation planning. Concludes that nearly all forms of outdoor recreation are susceptible to market analysis and that it is feasible to study markets to determine demand for and user's value of the types of outdoor recreation that guide user choices.

130. Dean, J. H., and C. S. Shih. 1975. Decision analysis for the river walk expansion in San Antonio, Texas. Water Resour. Bull. 11(2):237-244.

Recommends that the decision to expand the walkway should be based on the walkway's intangible attributes--such as recreational value and social impacts--as well as its tangible attributes--such as cost. Applies decision analysis techniques with multi-attribute utility theory rankings to assess tangible and intangible attributes. This method of decision making ensures that intangible benefits are considered.

131. Dwyer, John F., John R. Kelly, and Michael D. Bowes. 1977. Improved procedures for valuation of the contribution of recreation to national economic development. Res. Rep. 128, 218 p. Water Resour. Cent., Univ. Illinois, Urbana-Champaign, Illinois.

Presents procedures for evaluating criteria for water and related land resources. Federal agencies use the interim unit day value approach almost exclusively. This approach has little theoretical or empirical justification and does not encourage efficient allocation of resources. It is recommended that models be developed to predict individual willingness-to-pay for many types of recreation as functions of site characteristics, the characteristics of the individual user, the availability of substitute activities and sites, and the location of the individual in relation to the resources under study. The total value of the resource would be a function of these variables, the number of users, and the distribution of users within the market area. These functions may be derived from regional travel cost demand functions or could be explicit willingness-to-pay functions derived from the survey method.

132. Dyer, Allen A., and R. J. Whaley. 1968. Predicting use of recreation sites. Utah Agric. Exp. Stn. Bull. 477, 21 p. Logan, Utah.

Reports on an effort to produce a measurement model to predict recreation use. Assumes that other satisfactory models have been developed for predicting travel to competing market centers and for predicting market areas for shopping centers. Based on this assumption the measurement model is defined as a modification and combination of the gravity model and the theory of intervening opportunities. Suggests that these approaches to measuring use can be combined because both have the same influencing factors (available opportunities at site being examined, competing opportunities, and impact of travel distance).

133. Kelly, William F. 1970. Interrelationships among water-based recreation areas. *In* Western agricultural economics recreation Proc., p. 129-133. Oregon State Univ., Corvallis, Oregon.

Study on three Nevada lakes--Lake Tahoe, Pyramid Lake, and Lahontan Reservoir--to determine interrelations of demand for water-based recreation for specific sites. Author concludes that distance might not be a reliable substitute for price and that distance variables may often be highly interrelated. Suggests that other methods should be investigated in any further attempts to measure demand and demand interrelations for recreation areas. States that research should be conducted to measure recreational activities separately rather than as a whole because activities could be competitive.

134. King, David A. 1977. Economic evaluation of alternative uses of rivers. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 60-66. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Reviews the benefit-cost analysis decision criterion and the concept of opportunity cost. Outlines how to measure recreational benefits using the Hotelling-Clauson-Knetsch model. Discusses data and research needs for using benefit-cost analysis as a tool for making river management decisions. Concludes that the ability to use benefit-cost analysis in river management exists and should be exercised.

135. Knetsch, Jack L. 1971. Value comparisons in free-flowing stream development. Nat. Resour. J. 11(4):624-635.

States that current methods of evaluating recreation benefits are incapable of indicating how the demand curve changes with the type of recreation. The role of conventional prices in outdoor recreation is muted because a large portion of the cost is publicly provided. The availability of goods and services is as important for recreation as it is for other goods and services. There are two main considerations for estimating the values of the recreation opportunities that may be provided: (1) number of people it affects, and (2) user's willingness to pay.

136. Knetsch, Jack L. 1974. Outdoor recreation and water resources planning. Water Resour. Monogr. 3, 121 p. Am. Geogphys. Union, Washington, D.C.

Summarizes advances in existing techniques to quantitatively determine the demand for recreational opportunities and to estimate the value of such opportunities. Previous attempts to quantify recreational demand used projection models based on population, average income, and distance traveled to recreation sites. Some ways to estimate recreational values have been the market value method, cost method, willingness to pay, and gross expenditures method.

137. Krutilla, John V. 1970. Evaluation of an aspect of environmental quality. Soc. Stat. Sect. Proc. 1970:198-206.

Reports on a study to aid resource allocation decisions involving amenity aspects of the river environment of Hell's Canyon on the Snake River in Idaho. A comparative evaluation of the unique geomorphologic-hydrologic characteristics of the site and hydro-electric alternatives is made. Introduces a means of quantifying the costs and benefits of preserving the Canyon.

138. LaPage, Wilbur F., Paula L. Cormier, George J. Hamilton, and Alan N. Cormier. 1975. Differential campsite pricing and campground attendance. USDA For. Serv. Res. Pap. NE-330, 6 p. Northeast. For. Exp. Stn., Upper Darby, Pennsylvania.

Price differentials, including a premium for waterfront campsites and a preferential rate for State residents, were introduced at a New Hampshire State Park in 1973. Total revenue increased by 61 percent. Permit data before and after the change showed that attendance by State residents increased significantly. The differentials did not produce longer or more frequent visits by State residents nor a decline in the use of waterfront sites. Declines in visit length and party size appeared to be independent of fee policies.

139. Merewitz, Leonard. 1966. Recreational benefits of water resource development. Water Resour. Res. 2(4):625-640.

A pilot test of a demand model to measure recreationists' willingness to pay for various activities (boating, fishing, etc.) was conducted at Lake of the Ozarks in Missouri. The test identified four factors as necessary components of the demand model: population, population density, distance from the recreation site, and mean income of recreationists. Factors such as mobility and availability of alternative recreational activities did not appear to be useful factors for this model.

140. Michalson, E. L. 1977. An attempt to quantify the aesthetics of Wild and Scenic Rivers in Idaho. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 320-328. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Describes the procedure used to estimate demand for outdoor recreation on rivers. Also describes the development of a Likert-type scale to distribute the net resource values estimated in the demand analysis according to perceptions that users indicated as being important to the wild and scenic river experience.

141. Parent, C. R. Michael, and Franklin E. Robeson. 1977. Effects of National Park Service and Forest Service regulations on concession operations. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 334-341. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Examines the impact of USDA Forest Service and National Park Service regulations on the market structure of commercial float trip companies under their respective jurisdictions. Discusses price and quantity aspects of demand and differences in regulations.

142. Stern, Carlos David. 1974. Hydropower vs. wilderness waterway: the economics of Project Justification through the sixties. J. Leisure Res. 6(1):46-57.

Presents a critical review of the cooperative study by the U.S. Department of Interior's Bureau of Reclamation and National Park Service and the Army Corps of Engineers in the early 1960's. The study analyzes alternatives for developing the last major natural stretch of the upper Missouri River, scrutinizes recreation benefits at reservoirs and on wilderness waterways, and suggests willingness to pay and opportunity costs as two approaches to better measure such benefits.

143. Stevens, Joe B. 1966. Recreation benefits from water pollution control. Water Resour. Res. 2(2):167-182.

Presents a method for estimating direct recreation benefits from water pollution control using a model of biological-behavioral relations involved in sport fishing. Angling success per unit of effort was taken to represent the quality of the recreation experience. Direct recreation benefits were identified as fishing success per unit of effort that would result from the prevention of water pollution.

144. Stroup, R. L., M. D. Copeland, and R. R. Rucker. 1976. Estimation of amenity values as opportunity costs for energy-related water use in Montana. Montana Univ. Joint Water Resour. Res. Cent. Rep. 81, 51 p. Dep. Agric. Econ., Montana State Univ., Bozeman, Montana.

It is increasingly important that the value of water resources for nonconsumptive uses, such as recreation, be quantified. Numerous methods of site evaluation have been attempted but all have encountered problems stemming from the use of proxies for consumers willingness to pay for site use. A fee experiment for a specific site on the Yellowstone River is specified in detail. This method avoids the problems associated with proxies for consumer willingness to pay.

145. Trock, W. L., and R. D. Lacewell. 1973. An economic evaluation of a water-based urban tourist attraction in San Antonio, Texas. Tech. Rep. 48, 92 p. Water Resour. Inst., Texas A&M Univ., College Station, Texas.

Determines the economic effects of the Paseo Del Rio on commercial enterprises and activities as they relate to tourism and recreation in the central city. Three surveys were conducted. The first identified users of the walkway by their socio-economic characteristics and other factors important to their knowledge and use of the river. The second was a survey of businesses in the central business district, their economic characteristics, their relation to the river walkway, and the portion of gross receipts of these businesses attributable to the developed river area. The third survey identified characteristics of San Antonio residents, their knowledge of the river walkway, and their use of it.

146. Waller, Louis R., and Dwight R. McCurdy. 1977. A model for establishing water quality standards for rivers. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 380-385. North Cent. For. Exp. Stn., St. Paul, Minnesota.

An approach is presented for setting water quality standards for a river based on the following functional relation: R = f (Q, CQ, S, RC). Where R = recreation activities (in number of units), Q = water quality level, CQ = cost of achieving or maintaining a specific water quality level, S = recreational supply of the resource, and RC = recreational consumption. The approach is based on the assumption that the recreational use of a river is the most demanding of a high water quality compared to the other uses of the river.

147. Walsh, Richard G. 1977. Recreational user benefits from water quality improvement. *In* Economics of outdoor recreation Symp. Proc. USDA For. Serv. Gen. Tech. Rep. WO-2, p. 121-132. Northeast. For. Exp. Stn., Upper Darby, Pennsylvania.

Theorizes that upgrading the polluted waterways in the United States would result in a $7.3 billion increase in recreation users benefits (fishing, boating, swimming). Roughly $4.3 billion of this would be a savings in travel and time costs. Estimates do not include activities of youths 12 and under because of incomplete data concerning their water-based activities. Suggests further study on younger age groups. Also suggests research on benefits of incremental water quality improvement to determine what increase of benefits would result from a certain degree of water quality improvement.

INVESTIGATIONS OF ENVIRONMENTAL IMPACTS

(Also see reference numbers 12, 17, 29, 35, 40, 84, 102, 147)

148. Aitchison, Stewart. 1976. Human impact on the Grand Canyon. Down River 3(4):18-19.

Documents increasing use of the Colorado River through Grand Canyon National Park for river running and resulting biological and sociolcgical problems. Outlines a recent National Park Service research project to determine carrying capacities and the effect of the Glen Canyon Dam on the riparian environment. Suggests restrictive management of biologically sensitive areas within the Canyon as an alternative to limiting total numbers of rafters.

149. Aitchison, Stewart W., Steven W. Carothers, and R. Roy Johnson. 1977. Some ecological considerations associated with river recreation management. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 222-225. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Drawing from an ecological study on the Colorado River, four river recreation management concerns are discussed: (1) river research versus river management--their interrelations and priorities, (2) extensive resource inventories--their role as indicators of environmental deterioration, (3) human impact--its identification and proposed mitigation, and (4) suggested guidelines for identifying unique and ecologically sensitive areas. Also discussed are other environmental degradents not directly associated with human impact, but nevertheless a source of concern for river managers, such as habitat destruction by wild burros.

150. Barton, Michael A. 1969. Water Pollution in remote recreational areas. J. Soil and Water Conserv. 24(4):132-134.

The concentrated use of remote recreation areas, such as Minnesota's Boundary Waters Canoe Area, threatens water quality. Solid wastes, enriched waters from adjacent municipalities, human waste, gasoline from outboard engines, and insecticides all contribute to a potentially serious pollution problem. Natural inputs, such as sedimentation, must also be considered. Proposes a system for monitoring selected constituents (e.g., phosphorus, fecal coliform, etc.).

151. Cain, Stanley A. 1968. Ecological impacts on water resources development. Water Resour. Bull. 4(1):57-74.

Cites the historic lack of concern for the ecological side effects in water resources development and the resulting damage to the environment. Describes physical, biotic, and abiotic factors of aquatic ecosystems that are easily disturbed by man's alterations. Recommends funding of future baseline ecological studies.

152. Craig, William S. 1977. Reducing impacts from river recreation users. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 155-162. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Dramatic increases in river recreation use make it mandatory for managers to utilize the latest knowledge for preventing site degradation and maintaining a desired experience. Suggests that such innovative management as scheduling use, hardening sites, and improving human waste disposal, can make it possible for a Wild and Scenic River Area to support more people without lowering the visitor's experience or the environmental quality.

153. Davis, John H. (ed.). 1977. The big clean up: a special feature section. Parks and Recreation 12(2):4a-40a.

Entire section devoted to the implications of the Federal Water Pollution Control Act Amendments of 1972 to parks, recreation, and the leisure services delivery system.

154. Ditton, Robert B., David J. Schmidly, William J. Boeer, and Alan R. Graefe. 1977. A survey and analysis of recreational and livestock impact on the riparian zone of the Rio Grande in Big Bend National Park. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 256-266. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Visitor use patterns, biological conditions, and selected items of recreational impact (including litter, trampling, tree cutting, and human waste) were measured for 12 months. Use and impact were shown to be strongly and positively correlated. However, recreational impact was not significantly related to the biological "health" of the area. Cluster analysis was used to group areas into three categories based on degree of impact; only one of every four sites was heavily impacted. Principal component analysis identified human impact features as best discriminators between sites.

155. Dolan, Robert, Alan Howard, and Arthur Gallenson. 1974. Man's impact on the Colorado River in the Grand Canyon. Am. Sci. 62(4):392-401.

Describes environmental changes that have occurred along the Colorado River through Grand Canyon National Park, Arizona, since the Glen Canyon Dam was constructed. Cites major impact the dam has had on water level fluctuations and the subsequent effects this change has had on the vegetation, fish, beach formation, and rapids along the river. Also notes the increased effect of human use on the ecology of the Canyon. Suggests that quantification of river trip activity is needed to cope with human impact in the canyon/river environment.

156. Hansen, Edward A. 1975. Does canoeing increase stream bank erosion? USDA For. Serv. Res. Note NC-186, 4 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Describes research on the Pine River in Michigan to determine if large increases in canoeing accelerated stream bank erosion. Most erosion was natural, but people sliding and camping on stream banks created some erosion. Heavy canoe traffic is not a causal factor in erosion.

157. James, George A. 1974. Physical site management. *In* Outdoor recreation research: applying the results. Papers from a workshop held by the USDA Forest Service at Marquette, Michigan, June 19-21, 1973. p. 67-82. USDA For. Serv. Gen. Tech. Rep. NC-9, 113 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Notes that much information is available about the protection and maintenance of recreation sites, but the large number of resource variables and the highly specific nature of many research findings make it difficult to condense this information into a compendium of site management guidelines. Maximum use is apparently not being made of available site management information. Reasons include the highly scattered nature of information, difficulty in obtaining pertinent material, and research findings not always directly applicable to the problem at hand. A suggested reading list with 60 annotated articles on the subject is presented.

158. Kalnicky, Richard A. 1976. Recreation use of small streams in Wisconsin. Dep. Nat. Resour., Tech. Bull. 95, 20 p. Madison, Wisconsin.

A field survey of 80 small stream reaches was conducted to determine the amount of recreational use of small streams in Wisconsin. Both streams affected and those not affected by wastewater discharge were surveyed. The data suggest that there is only one-fourth to one-half as much recreational use on discharge-affected streams as on nonaffected streams. Study concludes that discharges from wastewater treatment plants apparently degrade the water quality on many small streams in a way that is noticeable to recreational users.

159. Knudsen, A. B., R. Johnson, K. Johnson, and N. R. Henderson. 1977. A bacteriological analysis of portable toilet effluent at selected beaches along the Colorado River, Grand Canyon National Park, Arizona. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 290-295. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Portable toilet effluent buried at nine beaches along the Colorado River in Grand Canyon National Park was examined for bacteria. Viable total and fecal coliforms were isolated 84 percent of the time. Coliforms were present throughout the strata to a depth of 2 feet. Concludes there is a definite public health hazard because of the numbers of coliforms and associated pathogens that are capable of surviving from one season to the next. Therefore, the health of the 15,000 individuals who annually make Colorado river trips and camp at such beaches is potentially endangered.

160. Kusler, Jon A. 1973. Carrying capacity controls for water recreation uses. Wisconsin Law Rev. 1:1-36.

Defines sociological and ecological carrying capacity and discusses possible methods to limit use: water-surface and shoreline zoning, permits, commercial restrictions, and access controls. Discusses legal considerations of the above controls and cites past litigation regarding riparian versus public rights. Presents a model statute designed to strengthen water and shoreland planning in Wisconsin.

161. Merriam, L. C., Jr., C. K. Smith, D. E. Miller, Ching tiao Huang, J. C. Tappeiner, II, K. Goeckermann, J. A. Bloemendal, and T. M. Costello. 1973. Newly developed campsites in the Boundary Waters Canoe Area. Univ. Minnesota Agric. Exp. Stn., Bull. 511, For. Ser. 14, 27 p. St. Paul, Minnesota.

Thirty-three wilderness campsites developed in the Boundary Waters Canoe Area during 1967 by the Forest Service were studied for 5 years (1968-1972) to determine the impact of visitor use. The effects on soils, vegetation, and site size were measured twice each year. Impacts were most severe in aspen-birch cover types and least severe in the white-cedar type. Impacts leveled off before the end of 5 years. Implications for wilderness management are also discussed.

162. Merriam, L. C., Jr., and C. K. Smith. 1974. Visitor impact on newly developed campsites in the Boundary Waters Canoe Area. J. For. 72(10):627-630.

The impact of visitor use on newly developed campsites tended to level off after the first 2 years. Visitor registration provided nearly complete use data, and the effects on soil, water quality, vegetation, and site size were measured and mapped. Physical measurements were combined into an impact-stage rating system by cover types. Management implications of the results are discussed.

163. Muratori, Alex, Jr. 1968. How outboards contribute to water pollution. The Conservationist 22(6):6-8, 34.

Discusses the design of two-cylinder engines and reasons for the large amount of exhaust produced. Presents new techniques to control pollution from outboard motors.

164. Schmidly, David J., and Robert B. Ditton. 1976. A survey and analysis of recreational and livestock impacts on the riparian zone of the Rio Grande in Big Bend National Park. 160 p. Dep. of Wildl. and Fish. Sci. and Dep. of Recreation and Parks. Texas A&M Univ., College Station, Texas.

Reports the results of a study conducted on the Rio Grande in Big Bend National Park. Study was organized into four parts: (1) visitor useage analysis; (2) subjective site evaluation; (3) biotic communities analysis; and (4) photographic recordings. Based on information uncovered in the study, recommendations are made for establishing a management framework. Various management strategies are also presented.

165. Settergren, Carl D. 1977. Impacts of river recreation use on streambank soils and vegetation--state-of-the-knowledge. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 55-59. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Various means of assessing recreational impacts on stream-side soils and vegetation have been employed to provide data to support and implement management decisions. Believes that past research in this area has usually been confounded by several problems. Suggests that the most critical research needs are: (1) selecting sampling points or sites to yield impact data representing an entire riverway; (2) randomly locating plots, points, and transects within a selected area; (3) locating suitable before-and-after or used-and-unused sites for control; (4) selecting and measuring the most important and most user-sensitive soil and vegetation features; and (5) measuring visitor use and how it correlates with impact data.

166. Stewart, Ronald H., and H. H. Howard. 1968. Water pollution by outboard motors. The Conservationist 22(6):6-8, 31.

Oil contamination is widespread and detrimental to water quality and marine life. A case study of outboard motor fuel pollution near a resort area is discussed. Estimates are made on the amount of fuel-pollution and its effect on the aquatic environment and on the continuing role of the area as a popular resort.

167. Tennant, Donald L. 1976. Instream flow regimens for fish, wildlife, recreation and related environmental resources. *In* Instream flow needs Symp. Proc. and Spec. Conf. Vol. II, May 3-6, 1976, Boise, Idaho, p. 359-373. Am. Fish. Soc., Bethesda, Maryland.

Describes a quick, easy method for determining flows to protect the aquatic resources in both warmwater and coldwater streams based on their average flow. Detailed field studies were conducted on 11 streams in 3 States between 1964 and 1974. This work involved physical, chemical, and biological analyses of 38 different flows at 58 cross-sections on 196 stream-miles, affecting both coldwater and warmwater fisheries. The studies reveal that the condition of the aquatic habitat is remarkably similar on most of the streams carrying the same portion of the average flow.

6
IDENTIFICATION OF USE AND USERS

(Also see reference numbers 12, 13, 14, 17, 27, 29, 30, 32, 35, 36, 37, 38, 40, 48, 50, 54, 72, 74, 81, 82, 83, 84, 90, 110, 111, 112, 113, 114, 123, 127, 132, 138, 139, 140, 143, 145, 147, 158, 164)

168. Ashton, Peter G., and Michael Chubb. 1972. A preliminary study for evaluating the capacity of waters for recreational boating. Water Resour. Bull. 8(3):571-577.

To determine the mathematical relation between use levels and user satisfaction, the quality of recreation experiences were examined for two groups of lake users in southeastern Michigan. Carrying capacity limits for boating were established, based on mailed questionnaires, personal interviews, and aerial photographs. Satisfaction was as important a variable in setting use limits as was the actual space available.

169. Barker, Mary L. 1968. The perception of water quality as a factor in consumer attitudes and space preferences in outdoor recreation. Assoc. Am. Geogr. Annu. Meet., Washington, D.C. (Mimeo)

Attempts to measure some of the social consequences of deteriorating water quality and the attitudes of people toward the recreational use of public waterways. Examines the relation between water quality evaluation and variables such as recreational activity, personal experience, and attitude toward the environment.

170. Baron, Norman J. E., James Cecil, and Philip L. Tideman. 1972. A survey of attitudes towards the Mississippi River as a total resource in Minnesota. Water Resour. Res. Cent. Bull. 55, 160 p. Univ. Minnesota, Minneapolis, Minnesota.

A survey of Minnesotan attitudes toward the use of the Mississippi River in Minnesota was conducted in 1971. Significant findings are that Minnesotans do not desire to curtail their uses of energy to improve the River's environmental quality, and that perceived present uses of the River are opposite to the uses of what the public desires.

171. Bassett, John R., Beverly L. Driver, and Richard M. Schreyer. 1972. User study: characteristics and attitudes Michigan's AuSable River. 78 p. Sch. Nat. Resour., Univ. Michigan, Ann Arbor, Michigan.

Discusses physical attributes of the AuSable River, biological impacts from human use, and economic impacts on the area from tourism. A survey of river users was conducted to determine user characteristics, conflicts among users, and other problems of use.

172. Boster, Mark A. 1972. Colorado River trips within the Grand Canyon National Park and Monument: a socio-economic analysis. Dep. Hydrol. Water Resour. Rep. 10, 83 p. Univ. Arizona, Tucson, Arizona.

Surveys river runners on the Colorado River through the Grand Canyon in Arizona to establish a social carrying capacity. Includes socio-economic information about users; user motives, expectations, perceptions, and satisfaction; and perceptions of river managers.

173. Boster, M. A., R. L. Gum, and D. E. Monarchi. 1973. A socio-economic analysis of Colorado River trips with policy implications. J. Trav. Res. 12(1):7-10.

Summarizes a study on the perceptions, expectations, and interactions of recreation users on the Colorado River through Grand Canyon National Park, Arizona. Suggests using both physical and biological factors to determine human carrying capacity of the Colorado River.

174. Branch, James R., and Stephen C. Fay. 1977. Recreation management planning for a multi-use scenic river corridor. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 142-146. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Thirteen Mile Woods is a highly scenic strip of forest land along the northern reaches of the Androscoggin River in New Hampshire. A survey of its visitors--canoeists, kayakers, picnickers, campers, fishermen, and snowmobilers--indicated their desire to maintain the area in its undeveloped condition. Land capability and administrative viewpoints indicated the same minimum development. Design capacity is discussed as a management concept for this land and river corridor.

175. Brewer, Durward, and Glenn A. Gillespie. 1969. Socioeconomic factors affecting participation in water-oriented outdoor recreation. USDA Econ. Res. Serv. ERS-403, 37 p. Washington, D.C.

Demand for water-oriented recreation by metropolitan populations can be estimated by assessing socioeconomic characteristics such as income, education, sex, race, occupation, and amount of leisure time. Results from a questionnaire given to St. Louis, Missouri, residents indicate that families with white male heads of households engaged in more outdoor recreation than families headed by nonwhites and women; demand for outdoor activities decreases with age; and higher income groups have more leisure time, more opportunities for recreation, and travel farther from home for outdoor recreation than do lower income groups.

176. Brickler, Stanley K., Douglas K. Larson, and Robert C. Johnson. 1974. Social carrying capacity of Grand Canyon Colorado River float trips: a conceptual framework. Inst. Renewable Nat. Resour. 40 p. Univ. Arizona, Tucson, Arizona.

Develops a three-phase conceptual framework for understanding and measuring aspects of social carrying capacity. Pretrip phase includes study of trip activity profiles, participant profiles, and user motivations. On-site phase includes study of actual float-trip where the individual encounters physical and perceptual sensations and experiences. Post-trip phase involves study of an individuals recollections about the float trip.

177. Brown, T. L., and G. R. Reetz. 1976. Swimming participation and water quality in Tompkins County, New York. Completion Rep., 53 p. Dep. Nat. Resour., Cornell Univ., Ithaca, New York.

A sample of Tompkins County households were surveyed to determine: (1) frequency of swimming, (2) frequency residents swim in waters not approved for swimming, (3) degree of public understanding and agreement with existing swimming standards, and (4) degree to which swimming is affected by perceptions of water quality. Findings indicate that most of Tompkins County's outdoor swimming occurs in natural area streams that are not regularly monitored by the local health department for water quality. Further, the majority of respondents could not give an evaluation on the degree of strictness of existing standards for swimming. Attitudes toward water quality appear to have some influence on swimming and the choice of a swimming area but other considerations such as convenience were more important.

178. Bryan, Hobson. 1977. Leisure value systems and recreational specialization: the case of trout fishermen. J. Leisure Res. 9(2):174-187.

A conceptual framework of trout fishermen is developed around the concept "recreational specialization". This refers to a continuum of behavior from the general to the specialized. It is reflected by equipment, skills used, and preferences for specific recreation setting.

179. Carlson, John E. 1974. Attitudes of Idaho residents toward free flowing rivers as a water use in Idaho. Scenic Rivers Study Rep. 12, 59 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Survey of Idaho residents to: (1) identify the importance of natural resources compared to other issues (e.g., education) and (2) identify the importance of wild rivers as a water use. Concludes that major resource priorities were in the areas of utilization and preservation and that Idahoans should approach resource use from a balanced perspective. The controversial area of wild and scenic river classification was supported even though attitudes were somewhat polarized. Suggests that attitudes should not be taken at face value alone but evaluated with respect to a person's overall priority rankings of various resource uses.

180. Christopherson, Kjell Arne. 1972. Report of an analysis of attitudes and opinions of St. Joe River basin landowners toward wild and scenic rivers. Scenic Rivers Study Rep. 2, 74 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Presents results of a survey of St. Joe River basin landowners on their attitudes and opinions towards the proposed inclusion of the St. Joe River in the National Wild and Scenic River System. Ascertains landowner/recreationist conflicts and the extent to which landowner's management policies and practices will be affected by such conflicts. Concludes that increasing public recreation facilities will substantially reduce such conflicts. Encourages active participation by private landowners in decision-making processes.

181. Christopherson, Kjell Arne. 1973. Attitudes and opinions of recreationists toward wild and scenic rivers: a case study of the St. Joe River. Scenic Rivers Study Rep. 9, 66 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Presents results of interviews with St. Joe River recreation users in 1971-1972. Focuses on the users attitudes and opinions toward the river's inclusion in the National Wild and Scenic River System. Responses favored river designation but concern was expressed for the intensity of development and recreational use the river might receive if designated.

182. Chubb, Michael, and Holly R. Chubb. 1975. 1974 Michigan recreational boating study. Recreation Resour. Consultants Rep. 4, 103 p. East Lansing, Michigan.

Presents results of a 1974 study on the amount, type, and pattern of use of licensed Michigan watercraft. Discusses and evaluates 19 factors that affect the reliability of the data and recommends how data collection can be improved for future studies.

183. Cieslinski, Thomas J. 1977. Allagash wilderness waterway. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 117-120. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Describes problems, solutions, and use experience during the first 10 years of managing the Allagash wilderness waterway. Problems related to increasing use include establishing public routes of access, registering users, dispersing users along the route of travel, restricting group sizes, establishing total use limits, and disposing of litter.

184. Clark, Roger N. 1977. Alternative strategies for studying river recreationists. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 91-100. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Recreation researchers have a variety of social research tools available to them. Often, however, the application of alternative tools in studying recreation issues is inconsistent with the strengths and weaknesses of the procedures. Alternative research strategies are discussed in terms of their ability to provide information to answer basic questions about recreation users and recreation problems. Implications for planners, managers, and policymakers are addressed.

185. Cordell, Harold K., Gordon A. Hammon, John Graham, William L. Hafley, and M. Roger Warren. 1975. Capacity of water-based recreation systems Part III: methodology and findings. Water Resour. Res. Inst. Rep. 90, 109 p. North Carolina State Univ., Raleigh, North Carolina.

Develops methods, models, and guidelines for planning and managing water-based recreation sites. Presents methods for collecting and processing data on the recreational behavior of boaters. Finds that capacity, measured as the number of boats on the lake system at the same time, is not a fixed number because most users seem to acclimate themselves to heavy use periods.

186. Driver, B. L., and John R. Bassett. 1975. Defining conflicts among river users: a case study of Michigan AuSable River. Naturalist 26(1):19-23.

Summarizes the findings of a 1971 Michigan study that examined the characteristics and attitudes of the river users (canoeists, fishermen, canoe outfitters, and cottage residents). Identifies primary areas of conflict as: (1) number and distribution of users, (2) motives of users, (3) user's perceptions of managerial problems, and (4) user reaction to controls on river use.

187. Driver, B. L., and John R. Bassett. 1977. Problems of defining and measuring the preferences of river recreationists. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 267-272. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Discusses seven broad types of problems experienced while researching the preferences of recreationists on three rivers in Michigan. Those problem areas concerned the tasks of: (1) selecting variables to be included in research designs; (2) deciding which research approach is best suited for particular purposes; (3) designing sample plans; (4) collecting data in the field; (5) understanding the dynamics of human preference formation; (6) defining the word preference; and (7) specifying clearly the preferences to be studied. Recommendations are offered for helping solve these problems.

188. Driver, B. L., and R. C. Knopf. 1976. Temporary escape: one product of sport fisheries management. Fisheries 1(2):21, 24-29.

Cites data from several studies to support the hypothesis that sport fishing helps people escape from stress experienced in home, neighborhood, and work environments. States that there are strong indications that stress levels within many individuals are increasing and that sport fishing is one way to relieve stress. Feels that more research into the value of sport fishing as a stress-relieving recreational activity is needed to enable managers of sport fisheries to better provide opportunities for this recreational activity.

189. Field, Donald R., and Neil H. Cheek, Jr. 1974. A basis for assessing differential participation in water based recreation. Water Resour. Bull. 10(6):1218-1227.

Data from telephone interviews of adult residents in western Washington, western Oregon, and northern California and data collected by observing recreationists using the coastal beaches of Olympic National Park, Washington, were used to identify factors associated with different participation patterns among recreation user populations. Comparison of these data suggests that recreation sites are perceived as leisure settings by both individuals and groups, and in that context possess a larger socio-cultural meaning than their strictly designed intent.

190. Gaumnitz, Jack E., Robert L. Smith, and John O. Tollefson. 1973. Simulation of water recreation users' decisions. Land Econ. 49(3):269-277.

Assumes that individuals have patterns of behavior that they consistently follow when making decisions about the kinds of recreation facilities to use and types of recreational activities to engage in while at a recreation site. Based on this assumption a simulation model was developed to reproduce the same behavior as an individual when given the same types of choices and decisions to make about the recreational sites. The model was designed with the same mechanisms individuals use to make decisions: memory, memory search, selection procedures, and a set of decision rules. These patterns of behavior can provide managers with a powerful tool to analyze choices and preferences of a population for predicting use rates at water recreation facilities.

191. Gillespie, Glenn A., and Durward Brewer. 1969. An econometric model for predicting water-oriented outdoor recreation demand. USDA Econ. Res. Serv. 402, 15 p. Washington, D.C.

Develops and tests an econometric model to estimate future demand at water recreation sites (lakes and streams). To test the model, 1,000 families living in St. Louis, Missouri, were randomly selected and surveyed in 1964. The model correlates socio-economic characteristics of survey group with water-oriented outdoor recreation activities such as swimming, fishing, boating, and water-skiing. Concludes income, age, sex, education, and occupation affect an individual's level of recreation participation and types of recreational activities pursued.

192. Godfrey, E. Bruce, and Robert L. Peckfelder. 1972. Recreation carrying capacity and wild rivers: a case study of the Middle Fork of the Salmon River. West Agric. Econ. Assoc. Proc. 45, p. 353-363. Logan, Utah.

Based on a 1971 study of use and users on the Salmon Middle Fork, three major factors were identified as necessary considerations for determining the River's recreational carrying capacity: (1) Legislation--the Wild and Scenic Rivers Act and the Wilderness Act provide administrators with general guidelines. (2) Environmental concerns--recreationists have negative impacts on the flora and fauna of the River environment. (3) User desires--major reasons given by recreationists for floating the River were solitude, scenic attractions, primitive atmosphere, and white water adventure.

193. Gordon, Douglas. 1971. A preliminary socio-economic analysis of hunting in Salmon River Basin: a methodology study to develop evaluation criteria for wild and scenic rivers. 44 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Sociological data and management-oriented information was collected from hunters in the Salmon River Basin during the 1969 hunting season. Expenditures associated with hunting were assessed. Hunter behavior, preferences, opinions, and place of residence were determined. Concludes that hunter expenditures associated with the wildlife resources are vital to the economy of the Salmon River Basin. Any development affecting wildlife resources--providing new access roads, improving existing roads, building more campgrounds and related facilities, or allowing more outfitters and guides--would have a negative economic impact on the Basin.

194. Graefe, Alan R. 1977. Elements of motivation and satisfaction in the float trip experience in Big Bend National Park. M.S. thesis. Dep. of Recreation and Parks, Texas A&M Univ., College Station, Texas. 170 p.

Presents results of a study of 329 river floaters on the Rio Grande in Big Bend National Park to determine the inter-relation between motivations and satisfaction in a float trip experience. Describes the most important motivations as: enjoyment, learning about nature, stress release/solitude, intra-group affiliation, challenge/adventure/achievement/photography/autonomy, extra-group affiliation, self-awareness and status. Measures of satisfaction were obtained by comparing importance and performance ratings for each motive. Concludes that Rio Grande float trips are perceived differently by different individuals and are capable of providing a variety of types of float trip experiences.

195. Gunn, Clare A., David J. Reed, and Robert E. Couch. 1972. Cultural benefits from metropolitan river recreation San Antonio prototype. Texas Water Resour. Inst., Tech. Rep. 43, 116 p. Texas A&M Univ., College Station, Texas.

Reports the responses of visitors, developers, and the voters of San Antonio to a recreation-business development complex along the San Antonio River in downtown San Antonio, Texas. Visitors describe the river-oriented development as beautiful, uncrowded, safe, and non-commercial. They claim it offers opportunities for a variety of leisure pursuits such as solitude, excitement, and sightseeing. Developers see the development as an informally designed landscape with provisions for many activities (business and recreation). Voters feel the development is a tourist attraction, is safe and clean, and they favor expanding the river development even if taxes would have to be raised to help pay for it.

196. Heberlein, Thomas A. 1977. Density, crowding, and satisfaction: sociological studies for determining carrying capacities. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 67-76. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Four types of carrying capacity are identified: physical, ecological, facilities, and social. The importance of both levels of technology and value judgments are noted for determining any of these capacities. The satisfaction model based on an explicit or implicit adoption of economic theory by both researchers and managers for determining social carrying capacity is lacking and an alternative model based on a determination of social norms is proposed. This model is discussed both in terms of recent social psychological studies of crowding as well as prior assessments of recreation carrying capacity. Finally, some practical suggestions for adopting this model are noted.

197. Heberlein, Thomas A., and Jerry J. Vaske. 1977. Crowding and visitor conflict on the Bois Brule River. Tech. Rep. WIS--WRC-77-04, 100 p. Univ. Wisconsin, Madison, Wisconsin.

Nearly 3,000 canoers, tubers, and fishermen were interviewed as they left the Upper Bois Brule River in the late summer of 1975 to determine their perceptions of crowding, satisfaction, and reported contacts with other visitors. In spite of daily use levels that were as high as 308 visitors on a 10-mile stretch, there was no relation between use levels and satisfaction. This study replicates prior research by Nielson and Shelby on Colorado River visitors, and casts more doubt on an econometric model of carrying capacity based on an assumed relation between use level and satisfaction of river users. All visitor groups expressed similar motivations for their visits, such as being close to nature, but differed in their level of commitment and background.

198. Howard, Gordon, John Bethea, Jr., Dee Kiger, and Rebecca Richardson. 1976. Chattooga River visitor survey. 75 p. Dep. Recreation and Park Administration. Coll. For. and Recreation Resour. Clemson Univ., Clemson, South Carolina.

Study about private and commercial users of the Chattooga River to develop: (1) a demographic profile of on-the-water-users, (2) a profile of water recreation users expectations, (3) a profile on users reactions to management options, and (4) a profile on users perception of river congestion. Study found that there is a difference between commercial and private users and their views toward management options. Commercial users rejected 8 out of 13 but private users rejected 15 out of 21 proposed management options and showed no majority concurrence on the remaining six. This difference may be accounted for partially because commercial users show their willingness to be managed by electing to use a commercial service.

199. James, George A., H. Peter Winkle, and James D. Griggs. 1971. Estimating recreation use on large bodies of water. USDA For. Serv. Res. Pap. SE-79, 7 p. Southeast. For. Exp. Stn., Asheville, North Carolina.

Describes a pilot sampling technique, originally tested on East Lake and Paulina Lake in Oregon in 1968, for estimating recreational use on large bodies of water. Includes recommendations for future sampling. Sampling technique included both ground observation and aerial counts of boats on the Lakes. Technique has application to measuring recreational use on rivers.

200. James, George A., Nelson W. Taylor, and Melvin L. Hopkins. 1971. Estimating recreational use of a unique trout stream in the coastal plains of South Carolina. USDA For. Serv. Res. Note SE-159, 1 p. Southeast. For. Exp. Stn., Asheville, North Carolina.

Presents results of a study conducted to estimate fishing use on a small trout stream in South Carolina. Simple random sample estimation procedures were tested and information was obtained for further refinement in use and cost estimation for trout fishing. Use was highly localized and only small costs were involved for fishing. Recreation and intangible benefits outweighed economic expenditures by fishermen.

201. Kaplan, Rachel. 1977. Down by the riverside: informational factors in waterscape preference. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 285-289. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Suggests that people like rivers and riversides because they provide both a sense of orderliness and a sense of involvement and mystery. The recreation value of rivers extends far beyond fishermen, boaters, and other traditional users. Even unspectacular rivers provide a source of enjoyment and tranquility for many who use only the riverbank, view the river from afar, or who only know that it is "there" and available. Stresses that because these passive users experience benefits similar to active users, their requirements deserve attention in design and management decisions. Suggests that ways must be found to involve passive users in decision-making so their diverse needs and concerns will not be overlooked.

202. Knopf, Richard C., B. L. Driver, and John R. Bassett. 1973. Motivations for fishing. *In* 38th North American wildlife and natural resources Conf. Trans. p. 191-204. March 18-21, 1973. Washington, D.C. Published by Wildlife Management Institute.

Discusses why people fish and engage in other recreation activities. Proposes that recreation management problems should be approached from a behavioral point of view. Identifies important forces that influence how people spend their leisure time and discusses progress in developing techniques for identifying and measuring recreational motives relevant to managers. Illustrates the use of these techniques to learn what motivates select groups of fishermen in Michigan. Concludes that increasing numbers of outdoor recreationists are using natural areas to temporarily resolve problems experienced at home and that serious consideration should be given to the degree to which opportunities should be provided in resolving these problems.

203. Lee, John. 1975. Collection and analysis of visitor use information: proposed upper Missouri wild and scenic river. 32 p. West. Interstate Comm. Higher Educ. and Dep. Recreation Park Manage. Univ. Oregon, Eugene, Oregon.

Presents data on visitor use from a 1975 study on the upper Missouri River by the Bureau of Land Management. Describes patterns of visitor use and develops user profiles based on socio-economic characteristics. Makes suggestions on regulating river use and provides guidelines to develop an informational guide for river floaters.

204. Lime, David W. 1971. Factors influencing campground use in the Superior National Forest of Minnesota. USDA For. Serv. Res. Pap. NC-60, 18 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

From a study of campground use in 1967 and 1968, relations were determined between the intensity of use and 74 site and location characteristics. Campers were interviewed to learn what factors influenced their choice of a particular campground. Outlines recommendations to managers and discusses topics for further research.

205. Lime, David W. 1972. Large groups in the Boundary Waters Canoe Area--their numbers, characteristics, and impact. USDA For. Serv. Res. Note NC-142, 4p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Discusses the impact of "large" parties in the BWCA in terms of their effect on the resource and on the experience of other visitors. Describes the amount of use by large groups and the visitors most likely to be affected by various party size limitations.

206. Lime, David W. 1975. Sources of congestion and visitor dissatisfaction in the Boundary Waters Canoe Area. *In* Quetico-Superior Foundation 1975 Institute on the Boundary Waters Canoe Area Proc. p. 68-82. May 9, 1975, Duluth, Minnesota. Quetico-Superior Foundation, Minneapolis, Minnesota.

Summarizes trends in visitor use since the advent of the Wilderness Permit in 1966. Also reviews a 1971 study of visitor attitudes and perceptions of crowding. Concludes that shifts in use suggest a greater significance of the Boundary Waters Canoe Area as a national wilderness resource. Discusses several management actions to reduce crowding.

207. Lucas, Robert C. 1964. The recreational capacity of the Quetico-Superior area. USDA For. Serv. Res. Pap. LS-15, 34 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

Visitor use of wilderness continues to grow each year, raising the question of recreational capacity and what are acceptable limits of use. Wilderness qualities were the main attraction for canoe trippers; other visitors considered fishing or scenery primary. Canoeists saw the wilderness as smaller than other visitors. Canoeists also felt the wilderness was overcrowded at lower levels of use and objected strongly to motorboats. A method for measuring capacity indicated total use is close to capacity, but more area is underused than overused. Use projections point to severe overuse. Implications for zoning and visitor regulations are discussed.

208. Lucas, Robert C. 1964. Wilderness perception and use: the example of the Boundary Waters Canoe Area. Nat. Resour. J. 3(3):394-411.

Examines the perception of wilderness by visitors to Minnesota's Boundary Waters Canoe Area. Discusses conflicts between user groups and between management policies and visitors. Compares perceptions of wilderness held by resource managers and various user groups. Outlines possible management alternatives for this area and similar wildland settings.

209. Lucas, Robert C. 1970. User evaluation of campgrounds on two Michigan national forests. USDA For. Serv. Res. Pap. NC-44, 15 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Campground use on the Huron and Manistee National Forests was studied in relation to resource characteristics, location, facilities provided, and visitor attitudes about the environment. Applies regression analysis to explain variation in campground use per unit. Compares visitor ratings of quality to nationwide Forest Service recreation resource inventories.

210. Maine Department of Conservation, Bureau of Parks and Recreation. 1974. 1973 survey of Allagash Wilderness Waterway visitor use and visitor use characteristics. 64 p. Augusta, Maine.

Presents results of surveys conducted in 1967 and 1972 of use on Maine's Allagash Wilderness Waterway. Data were collected on patterns of use and characteristics and motives of river users. Presents trends in visitor use since 1966. Concludes that because of congestion and user conflicts, efforts should be made to: (1) redistribute use over time and space, (2) separate small and large groups, and (3) develop separate sites for vehicle camping and picnicking from river floaters.

211. Matzat, Howard, John Benedict, and Dennis Myers. 1974. Land management report of users along the Stanislaus, Mokelumne, and Merced Rivers, during 1974. 27 p. Bur. Land Manage., Folsom Dist., Folsom, California.

Reports results of a 1974 spring survey of recreation use on the Stanislaus, Mokelumne, and Merced Rivers of California. Also presents a method for collecting future recreation use data.

212. McCool, Stephen F. 1972. Concept plan recommendations: Apple River recreation area. Tech. Rep. 1, 12 p. Univ. Wisconsin, River Falls, Wisconsin.

Describes tubing activities and high-density use on the Apple River near Somerset, Wisconsin. In 1971, an estimated 5,000 persons per hour floated on inner tubes down a short stretch of the Apple River. Concludes current overuse requires user control and management. Delineates a means of correcting the overuse problem through a method of self-management by the users.

213. McCool, Stephen F., and Lawrence C. Merriam, Jr. 1970. Factors associated with littering in the Boundary Waters Canoe Area. Minnesota For. Res. Note 218, 4 p. Sch. For., Univ. Minnesota, St. Paul, Minnesota.

Defines those variables most meaningfully related to sensitivity about litter and compliance with littering regulations. Discusses the role of outfitters in communicating and reinforcing norms. Examines the need for managers to establish relations with nonoutfitted groups in order to gain compliance.

214. McCool, Stephen F., and Lawrence C. Merriam, Jr. 1970. Travel method preferences of BWCA campers. Minnesota For. Res. Note 219, 4 p. Sch. For., Univ. Minnesota, St. Paul, Minnesota.

Probes the extent to which canoeists and motor boaters are satisfied with their method of travel. Examines the reactions of people toward other travel methods and discusses future patterns of use and management implications.

215. McCool, Stephen F., and Lawrence C. Merriam, Jr. 1971. Camper-outfitter interaction and the Boundary Waters Canoe Area, Superior National Forest, Minnesota. Minnesota For. Res. Note 225, 4 p. Sch. For., Univ. Minnesota, St. Paul, Minnesota.

Focuses on describing the communication processes of outfitters and wilderness visitors. In particular, identifies visitors' information sources and levels of knowledge about the Area and their attitudes on several important management policy issues.

216. McCool, Stephen F., and S. M. Haydock. 1976. Hikers of the Virgin River Narrows, Zion National Park. Institute for the Study of Outdoor Recreation and Tourism. 80 p. Utah State Univ., Logan, Utah.

Presents results of a 1976 summer study of day users and campers hiking in the Narrows. Data were collected and analyzed on: (1) total recreational use of the area, (2) socio-demographic characteristics of users, (3) recreational activity patterns, and (4) perception of users to hazards in the Narrows. Results showed that campers in the Narrows tended to be former day users. Also, although more than half the users were aware of the severe flash flood hazard in the area during the summer months, they were unaware of the probability of such a flood occurring.

217. Merriam, L. C., Jr., and Timothy B. Knopp. 1977. The complex uses of an accessible river--the Kettle of Minnesota. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 312-319. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Minnesota's Kettle River provides a wide range of recreation attractions--whitewater kayaking, canoeing, fishing, and boating--within 100 miles of the Minneapolis-St. Paul metropolitan area Initial results of a 1975-1976 study to develop baseline visitor data and a means of monitorin use suggest a complex of uses, visitor types, and river conditions.

218. Minnesota Outdoor Recreation Resources Commission. 1965. Recreational use of the St. Croix River. MORRC Study Rep. 11, 42 p. St. Paul, Minnesota.

A geographical and recreational description of the St. Croix watershed, including an inventory of recreation sites, general land uses, and ownership patterns is provided. Reviews laws and studies related to recreational use of the St. Croix. Presents selected recreation use statistics.

219. More, Thomas A., Robert O. Brush, and J. Alan Wagar. 1977. Variation and recreation quality in river management. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 329-333. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Suggests that variability in the river environment is a major determinant of the quality of river recreation experiences. Four main sources of variation exist for river canoeing: psycho-social, landscape, river, and the activity itself. By considering how these sources of variation interact, suggests that it should be possible to affect the quality of the recreation experience and accomplish other management objectives as well.

220. Munley, Vincent G., and V. Kerry Smith. 1976. Learning-by-doing and experience: the case of whitewater recreation. Land Econ. 52(4):545-553.

A household production model is used to show the impact of user experience on consumer behavior. Suggests that the more often an individual engages in an activity, such as white-water boating, the more skilled the person becomes at the activity and the more demanding the person is of a recreational site's services. Concludes that as experience and skill increase, a positive effect on the person's willingness to pay is observed but tends to level off as the desired degree of skill is reached.

221. Nicolson, J. A., and A. C. Mace, Jr. 1975. Water quality perception by users: can it supplement objective water quality measures? Water Resour. Bull. 11(6):1197-1207.

Personal interviews were conducted with 80 campers in each of 3 Minnesota State Parks to find how users perceived the quality of the water. Water quality factors were measured or observed as an indication of conditions experienced by the recreation users. Results indicate most people perceive water pollution on a visual basis only. Most felt that recreational activity did not contribute to water pollution. Two-thirds of the respondents felt their water recreation was not curtailed by water pollution.

222. Nielsen, Joyce McCarl, Bo Shelby, and J. Eugene Haas. 1975. Sociological carrying capacity and the last settler syndrome. Colorado River Res. Ser. Contrib. 8, 24 p. Human Ecol. Res. Serv., Boulder, Colorado.

Reviews literature on social carrying capacity and concludes that problems exist when trying to quantify capacity. Suggests that traditional user satisfaction models are probably inadequate to explain social carrying capacity. First-time users to a recreational area may have one threshold for crowding whereas persons who have visited a site more than once probably have a different threshold for crowding.

223. Nielsen, Joyce McCarl, and Bo Shelby. 1977. River-running in the Grand Canyon: how much and what kind of use. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 178-182. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Management issues relating to amount and kind of river-running use on the Colorado River in the Grand Canyon were investigated in 1975. Results show that use levels affect number of inter-group contacts, but number of contacts has little effect on perceived crowding or user satisfaction. Describes probable effects of an increase in oar trips.

224. Peckfelder, Robert L. 1973. Wild river perception and management: a study of users and managers of the Middle Fork of the Salmon River. Scenic Rivers Study Rep. 8, 108 p. Water Resour. Inst., Univ. Idaho, Moscow, Idaho.

During the summer float season of 1971, questionnaires were administered about the perceptions river managers have concerning the characteristics and attitudes of river floaters and the perceptions, attitudes, and characteristics river floaters have about themselves and river management. Data analysis show that Middle Fork River managers are in tune with floaters on their personal outlook of river management but have a poor idea of floaters' personal characteristics. Significantly more floaters than managers felt solitude should be an important part of the river experience.

225. Peterson, George L. 1974. A comparison of the sentiments and perceptions of wilderness managers and canoeists in the Boundary Waters Canoe Area. J. Leisure Res. 6(3):194-206.

Wilderness managers and summer canoeists were studied to determine whether the two groups differ in their wilderness motivations, attitudes, preferences, and perceptions of the Boundary Waters Canoe Area. Study indicates that managers have more varied motivations and more knowledge about the Area. Canoeists have an inflated image of the wilderness character of the Area but are more demanding in their expectations and use different criteria to evaluate recreational performance. The managers seem to be more cautious and realistic and less romantic and fanciful than the canoeists in their preferences for wilderness activities. Concludes that because of these differences, management services will be less than optional if the manager's decisions reflect his own attitudes and perceptions.

226. Peterson, George L., and Edward S. Neumann. 1969. Modeling and predicting human response to the visual recreation environment. J. Leisure Res. 1(3):219-237.

A method to predict user preferences for the visual recreation environment is proposed. Quantitative preference functions that respond sensitively to individual differences and characteristics of the environment are developed.

227. Pfister, Robert E. 1977. Campsite choice behavior in the river setting: a pilot study on the Rogue River, Oregon. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 351-358. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The relation of campsite choice to the natural characteristics of campsites was analyzed along the Rogue River in Oregon. Two regression models--for commercial and noncommercial camping parties--were formulated relating campsite choice to 13 site characteristics of river terraces. Of the five significant variables selected for each model, three were the same: size of the campsite, size of the tributary providing potable water to the location, and a rating of beach area available for landing a boat.

228. Pfister, Robert E., and Robert E. Frenkel. 1974. Field investigations of river use within the wild river area of the Rogue River, Oregon. Rogue River Study Rep. 1, 108 p. Dep. Geogr., Oregon. State Univ., Corvallis, Oregon.

Summarizes 1974 field survey to determine recreational carrying capacity and use levels along the federally designated wild area of the Rogue River. Revealed differences between commercial and noncommercial river travelers with respect to occupation, number of previous river trips, and membership in conservation organizations. Differences were also noted in commercial and noncommercial user's attitudes towards levels of crowding and potential use restrictions. River campsites were inventoried with respect to availability of potable water and enough flat ground to accommodate a camping party of four.

229. Recreation Resource Consultants. 1972. 1971 Michigan recreational boating study. Recreation Res. Consultants Rep. 2, 128 p. East Lansing, Michigan.

Presents results of the fourth Statewide boating survey. Questionnaires were used to obtain information on the amount, distribution, and nature of recreational boating by registered boaters in 1971. Estimates probable future boating use in Michigan and develops computer mapping techniques to show current and future distribution of boat use. Logistical problems of three previous Michigan boating studies are reviewed and recommendations are given on ways to improve future studies.

230. Reed, David J. 1976. The San Antonio River Walk: a user and environmental analysis. J. Soil Water Conserv. 31(1):28-30.

Reflects on the impact and effect of urban water development on users. Generally, user attitudes to urban river development are positive. Suggests diversity in design and development for success of urban river walkways.

231. Roggenbuck, Joseph W. 1975. Socio-psychological inputs into carrying capacity assessments for float-trip use of whitewater rivers in Dinosaur National Monument. 309 p. Ph.D. diss. Dep. For. and Outdoor Recreation, Utah State Univ., Logan, Utah.

Examines potential management strategies, perceptions of crowding, and sources of satisfaction for river users on the Green and Yampa Rivers in 1975. Different identifiable user groups varied in their responses to questions concerning recreational use of whitewater rivers as a function of differing expectations for the recreational experience.

232. Roggenbuck, Joseph W., and Richard M. Schreyer. 1977. Relations between river trip motives and perception of crowding, management preference, and experience satisfaction. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 359-364. North Cent. For. Exp. Stn., St. Paul, Minnesota.

River-floaters in Dinosaur National Monument were interviewed during the summer of 1975. Trip motives, in descending order of importance to users, were: action/excitement, learning about nature, stress release/solitude, affiliation, autonomy/achievement, self-awareness, and status. User scores on the motive-scales were related to user perceptions of river crowding, opinions on appropriate maximum group-size, campsite development strategies, river management techniques, and user satisfaction. A number of correlations were statistically significant, though relations tended to be weak. Management implications are also discussed.

233. Schafer, Thomas G. 1975. Management alternatives for the improvement of canoeing opportunities and the resolution of problems relating to the recreational use of rivers. Ohio Dep. Nat. Resour. Tech. Rep. 5, 181 p. Off. Plann. Res., Columbus, Ohio.

A three-phase study was conducted during 1974 in an effort to evaluate the needs and problems associated with canoeing in Ohio. The first phase was to gather information about other States' canoe programs to serve as a source of data on manager's viewpoints of how river recreation use and users should be managed. Phase two was to survey 1,000 Ohio canoe owners to identify their attitudes about management alternatives to problems of increased canoe use on Ohio's rivers. The final phase was to review and analyze phases one and two. Results of phase three identified the following alternatives to control use on the State's rivers: institute a permit system, increase the number of facilities and access points along some rivers, provide more campsites along rivers, and publish a "Guide to Ohio's Canoe Trails".

234. Schreyer, Richard. 1977. Satisfaction and user input to management. Utah Tourism and Recreation Rev. 6(1):1-7.

Proposes that the effectiveness of management decisions may be assessed by analyzing user input and scientific data. Defines recreation behavior and its main factors--past experience, expectations, and satisfaction. States that it is possible to associate recreational opportunities (canoeing, river running) with specific experiences (solitude, excitement) and that it is possible to manage for the experiences. Also includes results from a 1975 study on the Green and Yampa Rivers in Dinosaur National Park on recreation behavior and rivers.

235. Schreyer, Richard, Joseph W. Roggenbuck, Stephen F. McCool, Lawrence C. Royer, and Jay Miller. 1976. The Dinosaur whitewater river recreation study. 165 p. Institute for the Study of Outdoor Recreation and Tourism Dep. For. and Outdoor Recreation. Utah State Univ., Logan, Utah.

Reports the results of a 1975 study of users of the Green and Yampa Rivers in Dinosaur National Monument. Users were predominantly first time floaters and were overwhelmingly satisfied with the trip. Their most important expectations for the trip were found to be action/excitement, experiencing nature, and stress release/solitude. Recommends action managers can take to satisfy users but still minimize the effects of crowding and maintain a quality experience.

236. Seitz, William K., III. 1974. Patterns of recreational use and characteristics of users of the Upper Iowa River. Ph.D. diss. Iowa State Univ., Ames, Iowa. 193 p.

Examines recreational use on a 74-mile section of the Upper Iowa River in northern Iowa during 1972-1973. Data collected through personal interviews with river users and aerial counts were analyzed to identify the characteristics of users, use patterns, and user perceptions. Canoeing was the most popular and camping was the second most popular activity. Most canoeists used the river on weekends and holidays. Most users felt the river was becoming too crowded but wanted more facilities (campsites, tables, toilets, etc.) provided. Suggests that canoeing be dispersed more evenly to alleviate crowding.

237. Seitz, William K., and Robert B. Dahlgren. 1975. Water-based recreational use patterns of the Upper Iowa River. Iowa State J. Res. 50(2):131-145.

Describes a 1972-1973 study of recreational use on the Upper Iowa River. Canoeing, camping, fishing, and trapping activities were recorded and each were found to occur in distinct areas of the River (i.e., canoeing did not occur where trapping was popular). Canoeists and campers used the River more than fishermen or trappers. More than half of the canoeing and camping was on weekends and holidays.

238. Shafer, Elwood L., Jr., John F. Hamilton, Jr., and Elizabeth A. Schmidt. 1969. Natural landscape preferences: a predictive model. J. Leisure Res. 1(1):1-19.

People visiting the Adirondack's of New York State were interviewed during the summer of 1967 to identify significant quantitative variables in photographs that relate to public preferences for landscapes. Using factor analysis and multiple regression techniques, an equation was developed that accounts for the majority of variation in preference scores of landscape photos. Both the applicability of the model to resource planning and management and its limitations are discussed. Method has possible application for identifying riverscape characteristics preferred by recreation users.

239. Shaffer, Ron E., and Stephen F. McCool. 1973. Who's tubing down the Apple? Tech. Rep. 4, 31 p. Univ. Wisconsin, River Falls, Wisconsin.

Reports on the socio-economic characteristics of persons using innertubes to float the Apple River in west-central Wisconsin during 1971-1972. In 1971 social profiles and user attitudes were identified; in 1972 the economic impact of floaters on the local community was examined. Discusses interest of weekend and weekday users for more lodging and eating facilities in the immediate area. But found floaters contributed little revenue to the local economy.

240. Shelby, Bo. 1975. Social-psychological effects of motorized travel in wild areas: the case of river trips in the Grand Canyon. 66 p. Human Ecol. Res. Serv., Inc., Boulder, Colorado.

Reports results of two studies to evaluate potential motor/oar conflicts on the Colorado River through Grand Canyon National Park, Arizona: a pilot study in 1974 and a field study in 1975. Data from visitors traveling both by motor and oar power indicated that trip experiences differ on a number of characteristics including participant's background, opinions about motorized watercraft, number of encounters with other parties, and camping styles. Combination motor and oar powered trips were developed to observe same group behavior in both situations and to identify individuals preferences for one type of trip or the other. Floaters on combined motor and oar powered trips expressed a preference for the oar trip.

241. Shelby, Byron B. 1976. Social psychological effects of crowding in wilderness; the case of river trips in the Grand Canyon. Ph.D. diss. Dep. Sociol., Univ. Colorado, Boulder, Colorado. 180 p.

The effects of different use levels on crowding are discussed based on data collected on river trips in the Grand Canyon. The carrying capacity model traditionally applied to wilderness recreation is outlined, and then compared to a more general crowding model derived from research in other areas. Use levels have a pervasive effect on intergroup contacts, which in many ways define the "character" of the river experience. However, neither use levels nor contacts affect perception of crowding, and none of these variables affect passengers overall rating of the trip.

242. Shelby, Bo, and Joyce McCarl Nielsen. 1976. Design and method of the sociological research in the Grand Canyon. River Contract Study Final Rep. Part I, 32 p. Human Ecol. Res. Serv., Inc., Boulder, Colorado.

A pilot study of 11 trips was conducted during the 1974 river running season on the Colorado River through Grand Canyon. Final data was collected during the 1975 season by a stratified random sample of 46 commercial trips (39 motor and 7 oar) and 7 private trips. Four self-selected motor-oar combination trips provided additional data. Information sources included Park Service use records, trip reports by observers, and questionnaires and interviews from passengers and boatmen.

243. Shelby, Bo, and Joyce McCarl Nielsen. 1976. Motors and oars in the Grand Canyon. River Contract Study Final Rep. Part II, 42 p. Human Ecol. Res. Serv., Inc., Boulder, Colorado.

The effects of motor and oar trips in the Grand Canyon are discussed. Brief history of the controversy over motorized river travel is presented. Data on motor-oar differences come from two sources: people who were on either a motor or oar powered trip and people who were on a combination motor and oar powered trip. Combination trip passengers reported a clear preference for the oar trip. Implications for management are that (1) oar travel appears more compatible with the wilderness experience, and (2) a major increase in the proportion of oar travel would cause a number of changes in the river running scene.

244. Shelby, Bo, and Joyce McCarl Nielsen. 1976. Use levels and crowding in the Grand Canyon. River Contract Study Final Rep. Part III, 51 p. Human Ecol. Res. Serv., Inc., Boulder, Colorado.

Use levels affect the character of the river experience. Most river travelers define the Canyon and their trip as wilderness, and most perceive the Canyon as uncrowded. However, perception of crowding is independent of actual contact levels, and user satisfaction is unrelated to either perceived crowding or number of encounters. The lack of relation among these variables is attributed to the lack of agreement about how crowded the Canyon should be. Trip satisfaction was based on personal benefits, social atmosphere, and wilderness character the trip provided. Suggests that effective management of crowding should emphasize controlling the character of the river experience.

245. Shelby, Bo, and Joyce McCarl Nielsen. 1976. Private and commercial trips in the Grand Canyon. River Contract Study Final Rep. Part IV, 30 p. Human Ecol. Res. Serv., Inc., Boulder, Colorado.

Discusses the history of the private-commercial river trip controversy and summarizes arguments on both sides. Private and commercial users differ on a number of background variables and trips differ on structural characteristics. As a whole, the attitudes and perceptions of private users differ from those of commercial users, but are similar to those of commercial passengers taking oar-powered trips. Implications for management are discussed.

246. Shew, Richard L., and Michael P. Werner. 1976. Recreation use patterns and user attitudes on the Snake River. Final Tech. Rep., 114 p. Water Res. Cent., Washington State Univ., Pullman, Washington.

During the summer of 1971 mail-back questionnaires concerning the changes a proposed dam would have on recreational activities in the area were distributed to a sample of recreation users on the Snake River, Washington. Data showed that nearly all of the recreationists lived within 2 hours driving time from the River and that the River was their primary destination. Users were predominantly young to middle-aged and well-educated. The most popular recreation activities were sightseeing, fishing, hunting, picnicking, swimming, and relaxing. Most users felt present recreation opportunities were fair to excellent and that the dam would decrease the number and kinds of recreational activities available and cause overdevelopment of the area.

247. Sohn, Arnold J., and Arnold O. Haugen. 1969. How do Iowans use their lakes for recreation? Iowa Farm Sci. 23(9):8-9.

Studied competitive recreational uses on the Clear, Spirit, Okoboji, and Little Wall Lakes in Iowa during 1966-1967. Used pneumatic car counters, questionnaires, and time-lapse photography to describe recreational activity cycles on the lakes. Determined present and future areas of user conflict. Made the following recommendations to managers: limit boat size, zone lake areas by types of recreational uses, and manage waterfowl.

248. Solomon, Michael J., and Edward A. Hansen. 1972. Canoeists suggestions for stream management in the Manistee National Forest of Michigan. USDA For. Serv. Res. Pap. NC-77, 10 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

A survey of canoe use and opinions of canoeists on management practices along the Pine River in northwest Michigan was conducted in 1971. Users favored natural settings but did not object to the presence of streambank erosion. Also, canoeists viewed litter and crowding problems, but felt present levels of use on weekends and holidays were acceptable.

249. Stankey, George H. 1974. Criteria for the determination of recreational carrying capacity in the Colorado River Basin. *In* Environmental management in the Colorado River Basin. p. 82-101. A. Berry Crawford and Dean F. Peterson, eds. Utah State Univ. Press, Logan, Utah.

States that the Colorado River Basin offers a variety of recreational opportunities and, as such, can satisfy a wide range of user preferences and needs. All agencies responsible for managing and planning recreational use in the Basin and the public must be involved in determining the recreational carrying capacity of the Basin. Not only will their concerted efforts enhance existing opportunities but they will also open the door for new recreational pursuits. Presently the recreational planning efforts of various agencies have been isolated from each other, and the goals and objectives of these efforts frequently reflect the agencies biases.

250. Tarbet, Don, George H. Moeller, and Keven T. McLoughlin. 1977. Attitudes of Salmon River users toward management of Wild and Scenic Rivers. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 365-371. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Salmon River floaters were asked to answer a questionnaire that solicited their attitudes toward wilderness river recreation experiences and management. Factors relating to health and physical fitness, adventure, awareness of nature, communion with nature, and wilderness preservation were viewed favorably by nearly all respondents. Intensive management practices such as developed campsites, gravel roads and trails, picnic tables, garbage cans, and allowing power boats were rejected by almost all respondents.

251. U.S. Army Engineer District, Sacramento, California. 1976. Analysis of supply and demand of urban oriented nonreservoir recreation. IWR Res. Rep. 76-R2, 46 p. Appendix Inst. Water Resour., Fort Belvoir, Virginia.

Presents the results of research into the supply and demand of urban oriented nonreservoir recreation. Provides a detailed account of the data base used, the methods of collecting the data, and the analytical procedures followed in developing various recreation use prediction models. Recommends that the methods described be tested elsewhere, evaluated, and developed into a standardized procedure for use by the U.S. Army Corps of Engineers.

252. Van Doren, Carlton S., and Barry Lentnek. 1969. Activity specialization among Ohio's recreation boaters. J. Leisure Res. 1(4):296-315.

Participation in water oriented recreation is often characterized by strong activity preferences. More than two-thirds of a sample of recreational boaters in Ohio during 1966 specialized in either sailing, water skiing, pleasure cruising, or fishing (a fifth group was defined as nonspecialized). An analytical model is developed to identify the characteristics that differentiate boat activity specialists. Use of the model could have application to the study of rivers.

253. Warbler, Donald S., and Alan Jubenville. 1975. Perceptions and management preferences of users as a result of the commercial floating experience on the Snake River within Grand Teton National Park, 1975. 34 p. Dep. Recreation and Park Admin. Univ. Wyoming. Laramie, Wyoming.

Describes results of a study on individuals participating in commercial float trips on the Snake River in Grand Teton National Park. Regression analyses were used to identify independent variables that affect user satisfaction (seeing other rafts, man-made developments, interpretive talks, wildlife, etc.). Visitor satisfaction was high with respect to natural scenery, interpretive talks, wildlife, floating scenic waters, and relaxing on the trip. Seeing other rafts and crowding were somewhat neutral. Seeing man-made developments was a negative factor.

254. Welton, Brad, and Dick Harlow. 1973. California B.L.M. white-water use study. 72 p. USDI Bur. Land Manage. Folsom Dist., Folsom, California.

Summarizes the summer 1973 study on volume and use on the Stanislaus River in northern California. Also covers recreational use data collected for Mokelumne, Consumnes, South Fork of American, Merced, and Tuolumne Rivers. Contains information on the Stanislaus River about hazards, congestion at access and special interest points along the river, camping and picnicking sites, water quality, firewood availability, sanitation facilities, and types and volume of whitewater recreation use. Concludes that increased use of the Stanislaus has caused lowered water quality and serious crowding problems. Also includes information on the volume of recreational use the Mokelumne, Consumnes, Merced, Tuolumne, and South Fork of the American Rivers received.

7
MANAGEMENT OF RIVER RESOURCES

(Also see reference numbers 14, 18, 21, 23, 26, 27, 28, 39, 42, 44, 53, 55, 73, 84, 86, 96, 101, 117, 121, 128, 138, 142, 149, 152, 157, 158, 161, 162, 164, 167, 171, 174, 183, 185, 186, 190, 197, 201, 204, 205, 206, 207, 208, 210, 212, 213, 214, 215, 219, 221, 223, 225, 228, 230, 231, 232, 233, 234, 235, 236, 241, 243, 244, 245, 247, 248, 249, 250)

255. Allagash River Authority. 1965. The Allagash--Maine's counter proposal. Am. For. 71(2):26-29.

Summarizes a plan for State control of the Allagash River. Objectives of the plan are to outlaw the use of motors on boats and canoes, limit the use of aircraft in the area, restrict the size and location of campsites, confine timber harvesting operations to an area 300 feet from the river bank, forbid new public access roads within the waterway, and restore historical sites along the River for recreational use.

256. Chilman, Kenneth C., Leo F. Marnell, and Randall R. Pope. 1977. Developing a research capacity in field organizations to aid in management decisionmaking. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 163-167. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Discusses: (1) the trend toward developing research capacities in field organizations of national parks, recreation areas, or wildlife refuges; (2) factors that seem to be important in making such a research capacity most useful; and (3) some implications for education in recreational management and planning. Gives a detailed case history of the development of a river research program in one field location--the Ozark National Scenic Riverways in Missouri.

257. Gilbert, C. Gorman, George L. Peterson, and David W. Lime. 1972. Toward a model of travel behavior in the Boundary Waters Canoe Area. Environ. and Behav. 4(2): 131-157.

Focuses on the general overuse problem that exists in Minnesota's Boundary Waters Canoe Area and stresses the importance of determining social and ecological carrying capacities to prevent negative impacts of overuse. Proposes that once capacities are recommended, a predictive model can be used to evaluate the impacts of alternative use control measures. Identifies possible regulatory and manipulative use control techniques. Suggests Markov renewal theory as a promising tool to predict user distributions in dispersed recreation areas.

258. Harrison, Anne. 1977. Getting your story across--interpreting the river resource. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 125-138. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Suggests interpretation has special needs as it relates to river systems. These are discussed in light of the opportunities and problems associated with different sites, audiences, messages, and media. The appropriateness of media to river classifications is emphasized. Examples of interpretive services are used to illustrate the principle points of the discussion.

259. Hendrickson, G. E., and C. J. Doonan. 1972. Hydrology and recreation on the cold-water rivers of Michigan's southern peninsula. Geol. Surv. Water Inf. Rep. 3, 83 p. Lansing, Michigan.

Recreational values (e.g., trout fishing, boating, camping) of rivers are dependent on streamflow characteristics, water quality, and character of channel, bed, and banks. Generally, recreational value is enhanced by a relatively uniform streamflow. Suggests techniques such as preserving streamside vegetation to maintain water temperatures, controlling disposal of heated water to streams, and maintaining stream flow during drought periods, to manage streams for recreational values.

260. Jaakson, Reiner. 1971. Zoning to regulate on-water recreation. Land Econ. 47(4): 382-388.

Proposes a zoning system based on grouping those activities that exhibit similar density requirements and speed characteristics. Defines three activity zones: (1) a Shoreline Activity Zone, (2) an Open Water Zone, and (3) a Wildlife Zone. Guidelines for implementing the system are noted as are some of the legal, administrative, and ecological constraints that will necessitate certain alterations in the application of the model to different water bodies.

261. Kuska, James J. 1977. Biological approach to river planning and management. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 296-303. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The intent of Wild River legislation was to protect certain rivers for the benefit and enjoyment of present and future generations. Suggests that to accomplish this goal, river developers and managers must consider: (1) a riverway's ordered nature and inherent limitations; (2) which specific environments (soils, vegetation) and related variables (aspect, slope) along the river are best able to absorb recreational use; and (3) how much modification (vegetation and soil degradation) of a particular environment to accept before use is altered or limited.

262. Lewis, J. Harry. 1977. TVA's role in river-oriented recreation. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 139-141. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The Tennessee Valley Authority, in cooperation with other agencies and organizations, has surveyed a number of streams, acquired public access, developed parking and recreational facilities, prepared descriptive brochures, rated canoeing difficulty, and regulated streamflows from its dams. Suggests that providing use, not restricting it, is the agency's present course.

263. Lime, David W. 1969. Wilderness-like recreation opportunities adjacent to the Boundary Waters Canoe Area. Naturalist 20(1):36-41.

Suggests there are numerous wilderness-like recreation opportunities adjacent to Minnesota's Boundary Waters Canoe Area in the remainder of the Superior National Forest. If these opportunities were made known to potential recreation campers to northeastern Minnesota, demand and overuse in some portions of the Area could be substantially lessened. Notes the implications of these findings to water-based recreation management generally. Discusses some of the kinds of information needed to help recreation users choose among alternative areas and sites within areas.

264. Lime, David W., and George H. Stankey. 1971. Carrying capacity: maintaining outdoor recreation quality. *In* Forest Recreation Symp. Proc. p. 174-184. Northeast For. Exp. Stn., Upper Darby, Pennsylvania.

Discusses (a) what is meant by the concept of recreational carrying capacity, (b) what is known about capacities in terms of both how resources and experiences of visitors are affected by recreational use, and (c) what alternative procedures the administrator can use to manage both resources and visitors for capacity.

265. Mak, Kenneth R., Marvin O. Jensen, and Thomas L. Hartman. 1977. Management response to growing pressures in western white-water rivers--the art of the possible. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 102-109. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Describes agency responses to the increasing demand for whitewater recreation, development of management plans, and why planning and public involvement are needed. An example of conflicting interests and resulting political pressure is given.

266. Marnell, Leo F. 1977. Methods for counting river recreation users. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 77-82. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Recreation users on the Nation's rivers should be counted and classified. Procedures for documenting river use are reviewed and the merits and limitations of various approaches are discussed.

267. McCool, Stephen F., David W. Lime, and Dorothy H. Anderson. 1977. Simulation modeling as a tool for managing river recreation. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 304-311. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Accelerating use of free-flowing rivers for recreational floating has led many managers to set visitor use limits. The Wilderness Area Simulation Model was modified to predict patterns of river recreation use occurring under a variety of use conditions and was tested on the Green and Yampa Rivers in Dinosaur National Monument for the week of June 23-29, 1975. The "Base Case" simulation and actual patterns of use were compared and were found to be in close agreement. A variety of experiments, such as changing daily entry rates and opening and closing campgrounds, were simulated.

268. Peterson, George L., James S. deBettencourt, and Pai Kang Wang. 1977. A Markov-based linear programming model of travel in the Boundary Waters Canoe Area. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 342-350. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Describes and illustrates a Markov-based linear programming method used for predicting and analyzing travel in Minnesota's Boundary Waters Canoe Area so management can control the rate of entry of travellers into the Area.

269. Pfister, Robert E., and Robert E. Frenkel. 1975. The concept of carrying capacity: its application for management of Oregon's scenic waterway system. Rogue River Study Rep. 2, 50 p. Oregon State Marine Board and Water Resour. Res. Inst., Oregon State Univ., Corvallis, Oregon.

Increased recreational use of rivers has led to the examination of the carrying capacity concept and its management application as a basis to determine appropriate levels of seasonal use on Oregon's rivers. Proposes a set of principles based on the idea that an operational approach to carrying capacity is important in decision-making. States that although river management plans are not mandatory to implement the carrying capacity concept, they provide for a positive approach to river management.

270. Priesnitz, Michael. 1976. Minnesota's river program. Environmental Comment, June 1976. (A publication of the Urban Land Institute) p. 5-9.

Reviews provisions of Minnesota's Wild and Scenic Rivers Act. Discusses ways to preserve rivers through zoning and scenic easements. Notes the importance of effective communication with the public and the involvement of the public in carrying out program objectives.

271. Priesnitz, Michael F., and James Harrison. 1977. Managing corridors in multiple ownership. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 183-186. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Planning and management techniques for river corridors in multiple ownerships are described. The Lower St. Croix National Scenic Riverway between Minnesota and Wisconsin is used as an example.

272. Romesburg, H. Charles. 1974. Scheduling models for wilderness recreation. J. Environ. Manage. 4(2):159-177.

Scheduling recreation in wilderness areas is explored through mathematical modeling. A river system for recreational float trips is used as a hypothetical example.

273. Shane, Richard M. 1974. Riverine recreational development; mathematical modeling: final report. R74-6, 109 p. Dep. Civil Eng., Carnegie Inst. Tech., Carnegie-Mellon Univ., Pittsburgh, Pennsylvania.

Using a computer simulation model of water quality factors, a method was developed for assessing alternative urban riverine sites for recreation. The model gives statistical summaries of simulated water quality that can reflect changes in adjacent land use patterns and socio-economic characteristics of the landowners. Other modeling techniques used to estimate urban recreational use are also discussed. Evaluates the recreational potential for noncontact activities on the Allegheny River through Pittsburgh.

274. Sohn, Arnold J. 1968. Time-lapse movie camera for recording recreation activity cycles. Iowa Acad. Sci. 75:184-189.

Reports on the use of an 8-mm time-lapse movie camera to record information on daily, weekly, and seasonal patterns of recreational activities (e.g., waterskiing, fishing, boating, swimming) on Iowa lakes. Counting boats and identifying boat types was easiest when the camera was equipped with a zoom lens rather than a wide angle lens.

275. St. Croix Task Force. 1970. Wild waters of the St. Croix: a plan for preservation and management. 57 p. St. Croix Task Force, Minneapolis, Minnesota.

Identifies the environmental resources on the St. Croix River in Wisconsin and Minnesota that are worthy of preservation/restoration, and suggests methods to optimize management of the resources. Evaluates type and density of recreational use in the area and relates it to present facilities and management goals. To increase the tax base of the area, the private sector is encouraged to develop support facilities compatible with wild and scenic river status.

276. St. Croix Task Force. 1970. Wild waters of the St. Croix: a plan for preservation and management--addendum report. 78 p. St. Croix Task Force, Minneapolis, Minnesota.

Supplements the initial report. Contains information on shoreline controls, existing and proposed recreation facilities in the St. Croix-Namekagon area, and physical characteristics of the area.

277. Swanson, Earl J., Jr. 1970. The archeological resources of the Salmon River Canyon: a methodology study to develop evaluation criteria for wild and scenic rivers. 19 p. Water Resour. Res. Inst., Univ. Idaho, Moscow, Idaho.

Investigates the scientific and historical value of antiquities in the Salmon River Canyon. The Canyon shows evidence of a lengthy intercultural period and a rich history of man-environment relations. Discusses archeologically significant finds within the Canyon; past archeological research; funding problems; and time commitments required in archeological research. Has implications for interpretive management.

278. Tarlock, Dan A., and Roger Tippy. 1970. The Wild and Scenic Rivers Act of 1968. Cornell Law Rev. 55(5):707-739.

Reviews origins of legislation that led to passage of the Rivers Act and formation of the National Wild and Scenic Rivers System. Discusses the importance of acquiring lands along the river to provide a protective river corridor. Also reviews management guidelines established to protect rivers.

279. Terry, Claude E. 1976. Preserving an urban river: the Chattahoochee. Environmental Comment, June 1976. (A publication of the Urban Land Institute) p. 9-11.

Briefly describes the scenic and recreational attributes of the Chattahoochee River in the Atlanta metropolitan area. Discusses the combined efforts of local citizens and officials, State agencies, and Federal bureaus in aquiring land to preserve the Chattahoochee and its corridor.

280. Terry, Claude E. 1977. Citizen groups: their role in river recreational planning. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 210-213. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Suggests that the two equal and essential components that the river recreation planner must consider in decision-making are the managed space and the user who will inhabit that space. Believes use conflicts arise as the result of territorial interests of citizen groups. Notes that although the conflict between specific recreation users can never be fully resolved, the resource manager can adopt certain attitudes and actions to mitigate the conflict.

281. Warren, Sam E. 1977. How to ration river floating use: the Middle Fork of the Salmon experience. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 151-154. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Describes efforts by the Forest Service to limit float-trip use since 1972 on the Middle Fork of the Salmon River, Idaho. Notes the problems of finding equitable means of allocating permits between commercial and noncommercial parties and dealing with people without reservations.

282. Wilson, George T. 1964. Lake zoning for recreation: how to improve recreational use of lakes through regulation and control. 30 p. Am. Inst. Park Executives, Oglebay Park, Wheeling, West Virginia.

Offers guidelines for developing lake zoning ordinances and regulations. Provides administrators an understanding of the ecological problems involved in management of lakes for recreational purposes. Discusses the character of lakes, lake uses and activities, development cycle for lakes, space requirements for various uses, and the various means of regulation and control.

283. Yearout, Robert, Arthur Seamans, and Larry Lee. 1977. Regional river recreation management. *In* River recreation management and research Symp. Proc. USDA For. Serv. Gen. Tech. Rep. NC-28, p. 188-192. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Describes the evolution of the Interagency Whitewater Committee in the West, its present functions, and the potential of such agency coordination for the future (in the East and the West). Emphasizes the need for considering a regional approach to river management.

FEDERAL WILD AND SCENIC RIVERS LEGISLATION

(Also see reference numbers 7, 8, 10, 22, 47, 49, 50, 52, 57, 60, 61, 62, 63, 64, 67, 278)

284. U.S. Congress, Committee on Interior and Insular Affairs. 1968. An Act to provide for a National Wild and Scenic Rivers System, and for other purposes. (82 Stat. 906) 90th Congr. 1st. sess., P.L. 90-542. 12 p.

Legislative history: Senate Bill 119, Senate Report 90-491, House Report 90-1623, Conference Report 90-1917.

285. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1969. St. Croix National Scenic Riverway. 91st Congr. 1st. sess., House Document 91-165. 24 p.

286. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1969. Wolf National Scenic Riverway. 91st Congr. 1st. sess., House Document 91-166. 3 p.

287. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1969. Eleven Point River Plan, Mark Twain National Forest, Missouri. 91st Congr. 1st. sess., House Document 91-167. 41 p.

288. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1969. River plan for the Middle Fork of the Clearwater River. 91st Congr. 1st. sess., House Document 91-169. 31 p.

289. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1969. River plan for the Rogue River in Oregon. 91st Congr. 1st. sess., House Document 91-170. 56 p.

290. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1969. River plan for the Middle Fork of the Salmon River. 91st Congr. 1st. sess., House Document 91-171. 47 p.

291. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1969. The plan for the Rio Grande National Wild and Scenic River. 91st Congr. 1st. sess., House Document 91-174. 53 p.

292. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1969. Master plan for the Rogue River component of the National Wild and Scenic Rivers System. 91st Congr. 1st. sess., House Document 91-175. 108 p.

293. Federal Register. 1970. Allagash Wilderness Waterway Maine: notice of approval for inclusion in National Wild and Scenic River System as State administered wild river area. 35(138):11525-11526.

294. Federal Register. 1970. Middle Fork Feather Wild and Scenic River: classification, boundaries, and development plan. 35(45):4219-4222.

295. U.S. Congress, Committee on Interior and Insular Affairs. 1972. An Act to amend the Wild and Scenic Rivers Act by designating a segment of the St. Croix River, Minnesota and Wisconsin, as a component of the National Wild and Scenic Rivers System. (86 Stat. 1174) 92nd Congr. 2nd. sess., P.L. 92-560.

Legislative history: Senate Bill 1928, Senate Report 92-1279, House Report 92-1579.

296. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1972. A report on the Upper Iowa River, Iowa, pursuant to the Wild and Scenic Rivers Act of 1968. 92nd Congr. 2nd. sess., House Documant 92-379. 99 p.

297. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1972. A proposed combined Bureau of Land Management and Forest Service plan for the development, operation, and management of that segment of the Rogue River under the administration of the Bureau of Land Management and Forest Service in Oregon, which is part of the Wild and Scenic Rivers System. 92nd Congr. 2nd. sess., House Document 92-380. 224 p.

298. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1973. Recommending the addition of the Little Miami River, Ohio, to the National Wild and Scenic Rivers System. 93rd Congr. 1st. sess., House Document 93-184. 103 p.

299. Miscellaneous amendments pertaining to Wild and Scenic Rivers--never enacted into public law. 1973.

Legislative history: House Report 93-621, Senate Report 93-401.

300. U.S. Congress, Committee on Interior and Insular Affairs. 1974. An Act to amend the Wild and Scenic Rivers Act by designating the Chattooga River, North Carolina, South Carolina and Georgia as a component of the National Wild and Scenic Rivers System, and for other purposes. (88 Stat. 122) 93rd Congr. 2nd. sess., P.L. 93-279. 2 p.

Legislative history: House Bill 9492, House Report 93-675, Senate Report 93-738.

301. U.S. House of Representatives, Committee on Interior and Insular Affairs. 1974. Recommending the designation of the Lower Suwannee River to the National Wild and Scenic Rivers System. 93rd Congr. 2nd. sess., House Document 93-246. 120 p.

302. U.S. Congress, Committee on Interior and Insular Affairs. 1975. An Act to amend the Wild and Scenic Rivers Act (82 Stat. 906), as amended, to designate segments of certain rivers for possible inclusion in the National Wild and Scenic Rivers System: to amend the Lower St. Croix River Act of 1972 (86 Stat. 1174), and for other purposes. (88 Stat. 2094). 93rd Congr. 2nd. sess., P.L. 93-621. 3 p.

Legislative history: Senate Bill 3022, Senate Report 93-1207, House Report 93-1359, Conference Report 93-1645.

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Anderson, Dorothy H., Earl C. Leatherberry, and David W. Lime.
1978. An annotated bibliography on river recreation. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. NC-41, 62 p. U.S. Dep. Agric. For. Serv., North Cent. For. Exp. Stn., St. Paul, Minnesota.

River recreation is experiencing widespread growth and popularity and, as a result has become a major area for planning, management, and research. More than 300 citations documenting various aspects of the river recreation resource are presented.

OXFORD: 907.2:(048.1). KEY WORDS: Wild and Scenic Rivers Act, management, research, resource impact, carrying capacity, aesthetics, classification.

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USDA FOREST SERVICE
GENERAL TECHNICAL REPORT NC-42

elm ash cottonwood forest type bibliography

STEPHEN R. SHIFLEY
KENNETH M. BROWN

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

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ELM-ASH-COTTONWOOD FOREST TYPE BIBLIOGRAPHY

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The elm-ash-cottonwood forest type has been defined as the lowland forests where American elm (*Ulmus americana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), eastern cottonwood (*Populus deltoides* Bartr.), or silver maple (*Acer saccharinum* L.) comprise, singly or in any combination, the largest component of stocking. Common associated species include hackberry (*Celtis occidentalis* L.), American sycamore (*Platanus occidentalis* L.), black willow (*Salix nigra* Marsh.), and boxelder (*Acer negundo* L.). The elm-ash-cottonwood type occupies a large but irregular area on the floodplains and bottomlands of the north-central United States. Sites occupied by this type commonly have a high productive potential.

The literature search this bibliography is based on began with an extensive examination of Forestry Abstracts volume 24 (1963) through volume 37 (1976). Thus, this work is contiguous with the *Populus* bibliography of Farmer and McKnight. The bibliographies of major works found in the initial search of Forestry Abstracts were examined and many additional references were obtained. Several references found in this second search and published prior to 1964 were included when they seemed particularly relevant and had not been included in the Farmer and McKnight *Populus* bibliography. Finally, many current journals were searched for work that had not yet been reported in Forestry Abstracts. For addresses of many of the sources cited the reader may consult "Forestry Abstracts Coverage List"[1] or "List of Periodicals and Serials Regularly Scanned for Forestry Abstracts"[2].

During the initial examination of Forestry Abstracts, the following genera and species were actively searched: *Acer, A. saccharinum* L.; *Celtis, C. occidentalis* L.; *Fraxinus, F. pennsylvanica* Marsh.; *Platanus, P. occidentalis* L.; *Populus, P. deltoides* Bartr.; *Ulmus, U. americana* L. In addition, many references to *Salix nigra* Marsh. are cited.

Publications selected for this bibliography relate to one or more of the following broad subject categories: (1) Biology--includes references to life history, silvical characteristics, taxonomy, physiology, morphology, anatomy, and genetics; (2) Ecology--includes the topics of forest succession, allelopathy, soil site relations, flooding, and gradient analysis; (3) Silviculture--includes stand establishment, cultural treatments, harvesting methods, economics, and protection; (4) Mensuration--includes references to yield studies, mensurational techniques, growth prediction, and volume estimation.

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[1]Commonwealth Forestry Bureau. 1970. Forestry Abstracts Coverage List, October 1970. 20 p. Commonwealth Agricultural Bureaux, Farnham Royal, United Kingdom.

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In all cases interest was primarily in work dealing with natural stands. However, reports on plantations, greenhouse experiments, and other artificial situations were included whenever they were judged to be applicable to future studies of natural stands. Published abstracts have been cited whenever they were judged to contain significant amounts of useful information.

Citations obtained through Forestry Abstracts are followed by the Forestry Abstracts volume and entry number, e.g., FA 32:4773 refers to volume 32, entry 4773 of Forestry Abstracts. Users with access to Forestry Abstracts can thereby quickly locate a synopsis of these references.

A species and subject index and glossary of common insect names is provided for user convenience. Tree species and invertebrate organisms are indexed only by their scientific name. Vertebrate species are indexed only by common name. Cross references are used throughout to add clarity and to indicate categories where additional information may be found.

ACKNOWLEDGEMENT

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Glossary to the Scientific Names of Some Common Insects of Elm, Ash, and Cottonwood

Aphid	*Aphididae* spp.
Ash bark beetle	*Lepersinus aculeatus, Lepersinus californicus*
Ash seed weevils	*Thysanochemis bischoff, Thysanochemis hevola*
Bark beetles	*Scolytus* spp.
Biting midge	*Dasyhelea opressa*
Blotch leaf miner	*Paraleucoptera albella*
Branch borer	*Oberea delongi, Oberea schaumii*
Bronze poplar borer	*Agrilus liragus*
Carpenter worm	*Prionoxystus robinae*
Clearwing borer	*Paranthrene dollii, Paranthrene tricincta*
Columbian timber beetle	*Corthylus columbianus*
Cottonwood borer	*Plectrodera scalator*
Cottonwood leaf beetle	*Chrysomela scripta*
Cottonwood leaf curl mite	*Aculus lobulifera*
Cottonwood leaf miner	*Leucoptera albella*
Cottonwood twig borer	*Gypsonoma haimbachiana*
Double tail caterpillar	*Cerura wisei*
Eastern ash bark beetle	*Lepersinus aculeatus*
Epidermal miner	*Marmara* spp.
Elm bark beetle	*Scolytus scolytus*
Elm spanworm	*Ennomos subsignarius*
Elm spanworm parasite	*Telonomus alsophilae*
Eriophyid mites	*Eriophydidae* spp.
Fall cankerworm	*Alsophila pometaria*
Flat-footed ambrosia beetle	*Platypus sulcatus*
Flower flies	*Syrphidae* spp.
Fruit fly	*Aulacigaster leucopeza*
Hackberry butterfly	*Astercampa celtis*
Hackberry gall maker	*Pachypsylla* spp.
Hackberry blistergall maker	*Pachypsylla vesiculum*
Hackberry nipplegall maker	*Pachypsylla mamma*
Hackberry petiolegall maker	*Pachypsylla venusta*
Imported willow leaf beetle	*Plagiodera versicolor*
Lace bug	*Corythucha* spp.
Leaf curl midge	*Prodiplosis morrisi*
Leaf hopper	*Cicadellidae* spp., *Cuerna costalis, Erythroneura* spp., *Erythroneura lawsoni, Homalodisca coagulata, Oncometopia orbona*
Leaf-mining sawfly	*Messa populifoliella*
Leafroller moth	*Tortricidae* spp.
Native elm bark beetle	*Hylurgopinus rufipes*
Pin-hole borer	*Platypus sulcatus*
Poplar-and-willow borer	*Cryptorrhynchus lapathi*
Poplar borer	*Saperda calcarata*
Poplar tentmaker	*Icthyura inclusa*
Poplar vagabond aphid	*Mordvilkoja vagabunda*
Red spider mite	*Tetranychus telarius*
Serpentine leaf miner	*Gracillariidae* spp.
Shoot borer	*Gypsonoma aceriana*
Smaller European elm bark beetle	*Scolytus multistriatus*
Sycamore aphid	*Drepanosiphum platanoides*
Tent caterpillar	*Malacosoma fragile incura*
Viceroy butterfly	*Limentis archippus*
Wood gnat	*Mycetobia divergens*
Woodlouse	*Tracheoniscus rathkei*
Woolly pear aphid	*Eriosoma pyricola*

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Shifley, Stephen R., and Kenneth M. Brown.
1978. Elm-ash-cottonwood forest type bibliography. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. NC-42, 56 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Lists 679 references, arranged by author's names, on the biology, ecology, silviculture and mensuration of the elm-ash-cottonwood type and its component species. Indices for species, subjects, and second authors are appended.

OXFORD: 187:176.1 *Ulmus, Fraxinus, Populus*:(048.1).

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FOREST FIRE REPORTING BY THE NORTHEASTERN STATES

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protection requires careful planning based urate information on past, present, and ed fire activity. Recorded fire data, taken ndividual report forms, provide the major of information for this planning. The ness of fire protection plans, budgets, als, and administrative policies are fre- governed by the completeness and relia- f available statistics. In addition, standar- and accurate fire data provide important or fire management, fire prevention, and earch efforts.

e, conflicting, or inconclusive statistics are ng and frustrating for fire protection s. Moreover, erroneous conclusions can be f definitions of fundamental fire elements uniform. Thus, it seems imperative that lete, inaccurate, and conflicting data by different standards of reporting be ed. This paper documents data presently d on State fire report forms and suggests s for improving design of these forms as a ward uniform and accurate compilation of data.

FIRE REPORT FORM INFORMATION

nt and kind of information entered on fire t varies from State to State depending on actors as workload, management tech- budget restrictions, and legislative man- able 1). In 1968 the National Association of oresters requested a study of uniform fire nformation. As a result, a Task Force iden- asic items that should be reported by all re control agencies as of January 1, 1970 dix). Most States adopted but did not to- plement the recommendations.

Reported Fire Data

1. *Fire Location:* The most frequently used method of reporting fire location was by county, section, township, and/or range (the legal description), and district. Two of the basic items identified by the Uniform Fire Reporting Task Force were State and county where fire started. Although State is not included as a separate item, it appears on the heading of all the fire reports. County is present on 17 of the 20 forms. Only 25 percent of the States include watershed where fire started, an item strongly recommended but considered optional by the Task Force.

2. *Fire Cause:* Methods of reporting general cause vary and are somewhat ambiguous. Slightly more than 50 percent of the States use the nine general causes established and defined by the Task Force (Appendix). Of those States departing from these guidelines, three include all nine categories but substitute "machine use" for "equipment use". Two others follow the same pattern in addition to omitting railroad and/or children cause categories, and one State adds "lumbering" as a tenth general cause. Some States require the reporter to write in causes and others report specific causes, which vary widely from State to State.

General cause definitions differ greatly. Only one State follows word-for-word the Task Force basic definitions of general causes. A few use them but include additional explanations or instructions. Some States conform loosely to the Task Force definitions, and others don't conform at all.

Even though general causes are conceptually the same between the States, reporters may be classifying fires of the same cause under different

Table 1.—*Information included on individual fire report forms for 20 north-central and northeastern States*[1]

Reported Fire Data	Connecticut	Delaware	Illinois	Indiana	Iowa	Kentucky	Maine	Maryland	Michigan	Minnesota	Missouri	New Hampshire	New Jersey	New York	Ohio	Pennsylvania	Rhode Island	Vermont	West Virginia	Wisconsin	Total	Percent of States Reporting
Fire location[2]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Fire cause [2]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Acreage burned[2]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Date of fire[2]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Fire times	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Authorized signature	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Class of people responsible for fire	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Suppression activity[2]	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	19	95
Fire reported or discovered by	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X	18	90
Land ownership[2]	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X		X	X	17	85
Fire or report number	X	X		X		X	X	X	X	X	X		X	X	X	X		X	X	X	16	80
Fire danger and/or weather	X					X	X	X	X	X	X	X	X	X	X	X	X		X	X	15	75
Damage appraisal			X		X	X	X	X	X	X		X	X	X	X	X		X	X	X	15	75
Comments, remarks, or summary	X		X	X	X		X		X	X	X	X		X	X	X		X		X	14	70
Fuel and cover types		X	X	X	X		X	X	X	X		X	X			X		X		X	13	65
Law enforcement		X	X	X		X	X			X	X	X	X	X	X			X		X	13	65
Map of burned area		X	X	X		X	X			X				X		X		X	X	X	11	55
Size class[2]			X	X		X		X	X	X	X				X	X			X	X	11	55
Certainty of cause or origin		X					X		X				X		X	X			X		7	35
Railroads									X	X	X			X	X	X				X	7	35
Fire discovery reported to				X						X				X	X					X	5	25
Character of fire							X		X	X				X						X	5	25
Officer in charge of fire				X		X				X						X			X		5	25
Type of fire report						X		X	X				X		X						5	25
Fire originated under permit										X		X						X		X	4	20
Date of report			X									X		X							3	15
Fire tower										X		X	X								3	15
Date report received and investigated							X								X			X			3	15
Name of fire							X							X							2	10
Average tree size (d.b.h.)								X										X			2	10
Area burned before														X				X			2	10
Fire originated (highway; plantation)														X							1	5
If nonforest fire could fire have spread to forest?	X																				1	5
Number of sets																			X		1	5

[1] Some of the categories include a broad range of items pertaining to the same general topic, and in a few cases the data are not mutually exclusive. But, on the whole, the fire report information fits into these listed categories.
[2] Categories containing required and/or optional items recommended by the Uniform Fire Reporting Task Force (Appendix).

categories. This is due in part to nonuse of existing standardized terminology and to vague, incomplete, or nonexistent cause definitions.

3. *Acres Burned:* Because reporting methods for "acres burned" are so diversified, they preclude any detailed analysis of this classification. Acreage-burned categories range from one item to as many as 13. As States multiply the amount and complexity of acreage categories, they decr the number of mutually exclusive items. In a tion, reporting complexity is greatly increase the practice of combining under one item ac burned by land classification with those burne timber or cover type. Reporting efficiency data analysis would be greatly facilitated grouping similar items under one location on

and decreasing the number of reported ge categories to those required by the Task or to those actually used.

out 25 percent of the States utilize the Task recommendations by reporting acres d by both land classification and ownership ndix). Most of these, however, use different nology and add land classifications or owner- categories to meet their specific needs. ugh more than half report "acres burned" ne type of land classification, they omit re- g land ownership acreage. Forty percent e acres of naturally regenerated and/or ially regenerated land, which are items con- d highly desirable but optional by the Task Roughly the same percentage report "fire n arrival" and acreage of various vegetative

d 5. *Date and Time of Fire:* "Date of fire" is ed either as a separate item or as part of fire lassifications. Most States record the date nth, day and year but one reports the Julian code (1-365 days) and year; another, the month, and decade of the month; and one nents the month and day but no year! ugh only one-fourth specifically define the of fire as the time it started or was ered, nearly half record this item without larification. Rather than reporting this cate- s a separate item, the remaining 25 percent e the fire date with their fire time classifica-

"date fire discovered" by month, day, and a Task Force reporting requirement. Of the tes recording this item, 7 comply with this ement and 3 document only the hour of dis- rather than the date.

following times are reported by approxi- 75 percent of the States: fire start or origin, or attack, controlled, and extinguished. ss frequently reported times of discovery parture appear on one-third to one-half of e reports. In addition to the hour and/or s documented by all States for each fire tegory, 60 percent record month, day, and nd less than one-fourth include elapsed s

nhance accurate and efficient reporting, of fire" might be specifically defined as the date the fire started or was reported, or, more importantly, the date it was discovered—a Task Force requirement.

6. *Authorized Signature:* Signatures of fire personnel submitting, reviewing, and/or approving the report range from one to three. Approximately 60 percent of those requiring signatures record date-of-signatures as well.

7. *Class of People Responsible for Fire:* "Class of people" was not considered necessary for national statistics by the Task Force, but it is reported under several different formats. Half of the States record the name or name and address of the person(s) responsible for the fire. Nearly three-fourths supply class-of-people categories for the reporter to choose from. Of these about half indicate whether the landowner or occupant-tenant is responsible for the fire.

8. *Suppression Activity:* Suppression activity data consist primarily of personnel, ground equipment, transportation and supplies, and aircraft. Most States documenting personnel and ground equipment and the few recording aircraft-use report data such as number of people or equipment employed, type, hours worked, and wage or operation costs. In addition, a few include information such as travel method and distance to fire, amount of fire line constructed, man-hours to control, and method or type of attack.

Although the Task Force strongly recommended reporting cost class in order to stratify fires by approximate suppression cost, only a few States do; however, three-fourths report total suppression cost.

9. *Fire Reported or Discovered By:* Most reports include aircraft and lookout tower categories and, less frequently, categories of State and/or cooperating personnel and the public discovering or reporting the fire.

10. *Land Ownership:* Slightly less than half of the States reporting this item require the name and address of the landowner. The others include specific ownership classifications. Approximately one-third report land ownership in conjunction with their acreage categories.

The Task Force requirements include "ownership at start" of fire, and whether that ownership

is State, private, or Federal. At least two-thirds of the States comply with this requirement. In addition, several add more detail to ownership categories by including items such as county, municipal, railroad, highway, individual, corporation, or other.

11. *Fire or Report Number:* A fire or report number is assigned to each incident to avoid duplication. This distinct identity is important for filing and automatic data processing.

12. *Fire Danger and/or Weather:* Three-fourths of the States report information on fire danger and/or fire weather on the fire report forms. This includes components of the National Fire Danger Rating System (Deeming *et al.* 1972) and other various fire danger indexes. Weather data are usually restricted to wind speed.

13. *Damage Appraisal:* Damages are recorded as monetary losses, commercial and/or noncommercial forest land losses and in some cases volume of timber lost. Other major reported damage categories include nonforested land, wildlife, recreation, real property, personal property, and watershed.

14. *Comments, Remarks, or Summary:* This item is used to clarify what is recorded in other data spaces or to document additional important information so that someone not present at the fire will understand what happened. One to two lines to half a page are allocated for this item on State fire reports.

15. *Fuel and Cover Types:* The fuel categories listed appear to be specific breakdowns of the three major land classifications specified by the Task Force: commercial forest land, noncommercial forest land, and nonforested watershed. General fuel or cover types most frequently reported include conifer, hardwood, and nonforest land such as grass, pasture, marsh, brush, and shrubs. A few States record National Fire Danger Rating System fuel models in addition to the data above.

16. *Law Enforcement:* Law enforcement items include law violations and/or action taken in the form of prosecution, conviction, or monetary settlement. One-third of the States report the outcome of court cases, and only a few require information on suspects, motives, witnesses, or evidence.

17. *Map of Burned Area:* Slightly more half of the States use maps to indicate locatio fire in relation to topographic features. Re map information includes distance, cardinal tion, wind direction, and fire starting Almost all the reports with maps have a divided rectangular map for reporting the description of a fire.

18. *Size Class:* Fire size class is required Task Force for uniform fire reporting. Ap mately half of the States reporting this ite the size classes recommended by the Task (Appendix).

19. *Certainty of Cause or Origin:* Data rel ty is assessed by assigning a scale of certai observer confidence in fire report entrie some reports certainty scales are assigne marily to fire cause and time of origin. One also applies them to person-responsible-f and to land ownership categories. Most State four certainty categories—possible-known, able-known, estimated-known, and probable tive.

20. *Railroads:* The wide variation of ra information reported includes the name o railroad responsible for the fire, fire cause, and/or locomotive number, direction of t and mile-post or location.

21. *Fire Discovery Reported to:* This ref the name or title of the individual or s receiving the first report of the fire.

22. *Character of Fire:* This item refers t behavior on arrival and fire type. Although t nology and specific breakdowns of these vary, the basic fire types to emerge in ground fires, surface fires, and crown fires.

23. *Officer-in-Charge of Fire:* Some State port the officer-in-charge, the person in cha suppression action, apart from their fire sup sion data. The officer's name and addres most frequently reported.

24. *Type of Fire Report:* These data ca used to indicate the amount of suppression e ment and personnel devoted to nonstatistical such as false alarms. Some of the categories to report types of fire are: forest fire, wood endangered, reportable, violation, legal

alarm, nonservice, blowover, nonstatistical, ıpplemental.

Fire Originated Under Permit: Most of the reporting this item require a yes or no entry ting whether or not a wildfire originated a permit to burn.

Date of Report (Month, Day, Year): Date of usually refers to the day of fire report com- ı. It's often used for internal monitoring of port processing time.

Number of Sets: In discussing reportable nd, in particular, multiple sets such as a of incendiary or railroad fires, or lightning , the Task Force states that the number of able fires would be determined by the r of separate, final, control perimeters. lso maintain that the number of sets should icated for each reportable fire. Only one provides space for this on its fire report

A Step Toward Uniformity

mparison of the State fire report data indi- four common problems: (1) lack of standard ology and reporting procedures; (2) ambi- item labeling; (3) duplicate reporting; and orporation of excess information.

se problems could be minimized by adopt- e following suggestions. First, update the sary of Terms Used in Forest Fire Control" . Forest Service 1956) to include more terms n the reporting process, and utilize the Uni- Fire Reporting Task Force recommenda- Second, state specifically in item captions formation desired and include a clear expla- of that item in the report form instructions. l eliminate duplicate report items and excess formation by re-evaluating and redesigning e report form.

DESIGNING A FIRE REPORT FORM

following three questions must be consi- when designing a fire report form (see also al Archives and Records Service 1959, 1960 re information):

at information is essential?

w should this information be entered, uped, and sequenced on the form?

3. How could these data be modified to produce information that is properly coded and formatted for computer use?

Essential Information

Question the need for each item. When a form is completed hundreds or thousands of times, one item will represent many hours of work.

An item can be eliminated from a fire report if:

1. It includes information no longer needed.
2. There's an alternate source or better way of obtaining the information.
3. The data it collects costs more than it's worth.
4. It can be combined with another item.

Form Preparation Methods

Properly group items on the form. If items pertaining to the same subject are scattered over the fire report working area, the form generally requires more time to complete and to use. For example, one State reports plantation acreage apart from other acreage categories. In contrast, acreage-burned items are properly grouped in figure 1. Item grouping not only reduces travel and positioning of the hand or typewriter carriage in form completion but also reduces eye movement in finding items for extraction and review.

Sequentially arrange form items to follow the flow of work and, therefore, the habitual way of thinking about matters in the office or field. This increases the speed of entering or extracting data from a form by minimizing hand and eye movement. On one fire report, for instance, "discovered by" and "reported to", are reported *after* "travel to fire", and other fire action data. Chronologically they precede fire suppression activity and should be reported in advance of these items. In contrast, items contained on the fire report in figure 1 generally follow an orderly chronological sequence. The report begins with basic fire data including date, fire location, cause, and ownership, and proceeds with a description of the actual fire sequence including discovery, attack, fire situation on arrival, fire danger variables, and so forth.

Select the proper form style to improve report design. Prior to the 1920's, the captions-on-the-line form design style was most popular (fig. 2). Although variations of this style are used by 60

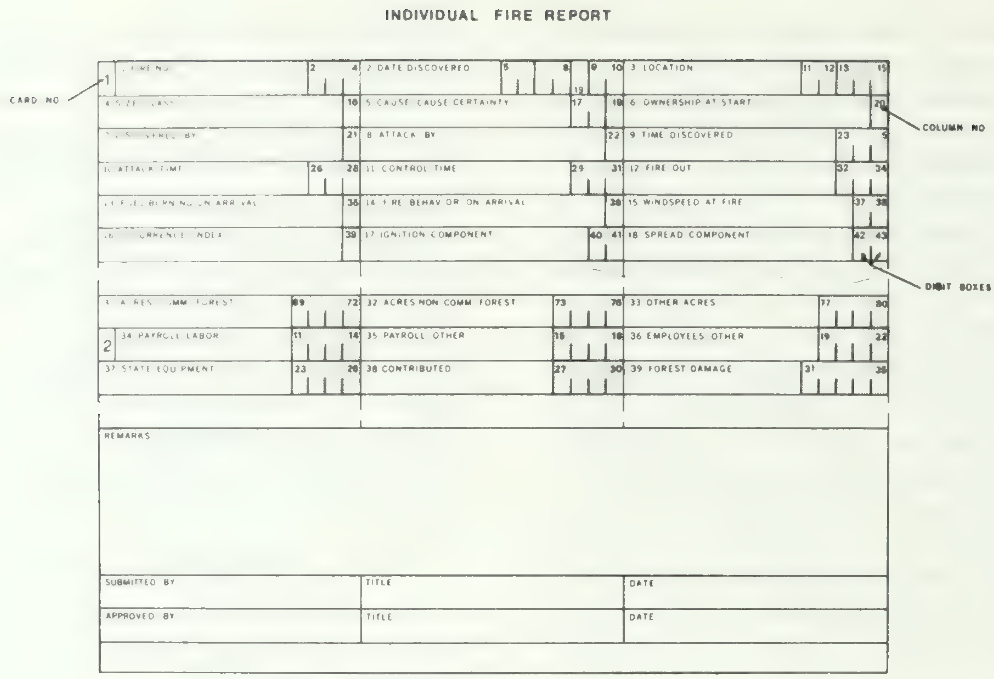

Figure 1.—*Illustrations of item grouping and sequencing, box design, computer punched-card and column numbers, and shaded digit boxes on a hypothetical fire report form.*

percent of the States, it's no longer recommended. It robs space, wastes motions, defeats the use of typewriter tab stops, impedes reading, writing, and interpreting, and appears ragged.

A good, workable method is the box design in which the caption and entry space for each item on the form are included in a box (fig. 1). Captions are printed in small, distinct type in the upper left hand corner of the boxes, which leaves the entire width of the box free for fill-in.

This design, which is used by less than one-fourth of the States, is recommended because it saves space, avoids wasted motions, and makes use of typewriter tab stops. Because data entered on the form correspond to visual habits (i.e. left to right, top to bottom), the design also aids reading, writing, and interpreting. And, due to alignment of vertical rules and a common left margin, form appearance is streamlined.

Consider the size of the fire report. If a file is referred to frequently, any printing savings from a small form usually can be more than offset by the cost of additional clerical time required in searching the files. At the other extreme, an oversize form forced into a letter-size file by folding the report to fit, slows down file searching.

Finally, supply instructions for readers to int[erpret] the fire report so they may supply accur[ate] answers or efficiently process the form. Few [if] any, fire reports are self-explanatory. They m[ost] often require detailed instructions published [in] directives, manuals, or in other issuances alo[ng] with a sample form keying the instructions [to] specific items.

Automated Data Processing

Because punched cards are the most wid[ely] used computer compatible medium, the follow[ing] general guidelines will improve the data trans[fer] capability from fire report forms to punched car[ds].

In order to eliminate the unnecessary step [of] manually posting data from a fire report to a [code] sheet for keypunching, design a form that faci[li]tates data transcription from descriptive words [to] numerical codes suitable for computer processi[ng]. This may be done by including column a[nd] punched card numbers directly on the fire repo[rt]. Column numbers usually appear to the right of [the] caption identifying each item on the report. T[he] card number is necessary only if more than o[ne] card is used per report and is located in the up[per]

1. LOCATION: County ____________________; _______Miles (E) (S) (N) (W)

of ________________________ on Route # _________________.

2. OWNERSHIP AT START: ____

OTHER LANDOWNERS: Name ____

Address ____

3. FIRE STARTED ___A.M. ___P.M.; FIRE REPORTED ___A.M. ___P.M.

FIRE SIZE ON ARRIVAL: __________________ Acres

Figure 2.—*An example of a captions-on-the-line form design style.*

and corner of each block of information (fig. 'orms without column or card numbers ase the chance of keypunching error and verification of completed cards difficult.

addition to column numbers, include digit s that enhance data processing procedures by lly indicating the number of codes, corre- ling to the number of punched card columns, ed for each item (fig. 1). Without these , errors may occur in the number of digits red for each item.

color to provide the data-processor with visual cues for locating and extracting coded Shaded boxes (fig. 1) or colored ink are l for this purpose. Some colors like red and e can be irritating and tiring.

one-sided report is easier to keypunch se it eliminates the need to turn each report tinue data processing. Also, make sure the sequence on the fire report and punched is identical, and arrange coded data to read eft to right and top to bottom, following the habits of the data processor.

other option to including column numbers igit boxes with each fire report item, is to them in a separate section on the report This concentrates coded data into one area, facilitates the keypunching process by re- g eye movement and increasing the speed fficiency of data processing.

ally, carefully examine each completed ed card for errors, and store cards not in use pressure with proper temperature and lity controls to assure their safekeeping.

As demands upon fire management become greater and more complex, the job necessitates systematic, automated data processing. This requires a well-designed fire report form that not only contains essential, properly arranged information, but also includes a satisfactory method of transferring data from the form to a computer compatible medium. This stored information, coupled with some familiarity of computer capabilities, allows the fire manager to tap that information base for a wealth of summarized output.

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Deeming, J. E., J. W. Lancaster, M. A. Fosberg, R. W. Furman, and M. J. Schroeder. 1972. National fire-danger rating system. USDA Forest Service Res. Pap. RM-84, 165 p., Rocky Mountain For. and Range Exp. Stn., Fort Collins, Colorado.

USDA Forest Service. 1956. Glossary of terms used in forest fire control. U.S. Dep. Agric., Agric. Handb. 104, 24 p.

National Archives and Records Service. 1959. Managing forms: forms analysis. A Records Manage. Handb., 62 p., United States Government Printing Office, Washington, D.C.

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APPENDIX

The National Association of State Foresters at an October 1968 meeting in New Orleans, Louisiana, adopted a resolution pertaining to uniform fire reporting. In essence the resolution, noting the continued discrepency in the manner of reporting forest fires in the United States, stated that the Association believed considerable benefit would result from a uniform system of forest fire reporting by all agencies in all sections of the country. Furthermore, they requested that the U.S. Forest Service make a study of uniform forest fire reporting under guidelines developed by a Steering Committee assisted by a Task Force.

As a result, a Steering Committee and Task Force, composed of representatives from the National Association of State Foresters and Federal protection agencies, convened and developed a list of recommendations. Some of the more pertinent points follow:

1. The goal of uniform fire reporting is acceptance by all agencies of applicable common definitions and the uniform reporting of specified, agreed upon items of data.

2. The following terms have been defined and acceptance is required for a uniform fire reporting system:

   a. Wildfire
   b. Reportable Fire
   c. False Alarm
   d. Commercial Forest Land
   e. Noncommercial Forest Land
   f. Nonforested Watershed Land
   g. Wildfire Size Classes (Classes A-G)
   h. Wildfire Cost Classes
   i. General Causes
      1. Lightning
      2. Campfire
      3. Smoking
      4. Debris Burning
      5. Incendiary
      6. Equipment Use
      7. Railroad
      8. Children
      9. Miscellaneous

3. The following eight basic items are req[illegible] from all agencies for uniform reporting:

   a. Reporting Agency
   b. State (Where Fire Starts)
   c. County (Where Fire Starts)
   d. Date Fire Discovered (Month, Day, Y[illegible]
   e. General Cause
   f. Ownership at Start (State, Private, Fe[illegible]
   g. Acres Burned By:
      1. Land Classification
         a. Commercial Forest Land
         b. Noncommercial Forest Land
         c. Nonforested Watershed
      2. Land Ownership Status (State, Pri[illegible] Federal)

   h. Size Class (A-G)

Size Class	*Acres*
A	0-0.25
B	0.26-9
C	10-99
D	100-299
E	300-999
F	1,000-4,999
G	5,000 and over

4. The following four items were considered [illegible]ly desirable, but were listed as optiona[illegible] cause of the possible administrative bu[illegible] involved in reporting them:

   a. Watershed Where Fire Started
   b. Acres of Naturally Regenerated Fores[illegible] Burned
   c. Acres of Artificially Regenerated Fore[illegible] . Land Burned
   d. Fire Cost Class

The Task Force made clear that the "[illegible] Items" of information are the *minimum* fores[illegible] statistics required for the nation as a whole. T[illegible] items were to be *reported uniformly by all f[illegible] fire control agencies in the United States.* [illegible] target date for uniform reporting was Janua[illegible] 1970.

☆U.S. GOVERNMENT PRINTING OFFICE: 1978—768-359/1[illegible]

Donoghue, Linda R.
1978. Forest fire reporting by the northeastern States. U.S. Dep. Agric. Gen. Tech. Rep. NC-43, 8 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Documents data presently recorded on 20 State fire report forms, suggests ways to improve the design of these forms, and outlines methods to transfer data to computer-punched cards.

OXFORD: 431.1(74). KEY WORDS: Fire records, automated-data-processing, fire management.

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OXFORD: 431.1(74). KEY WORDS: Fire records, automated-data-processing, fire management.

Man paints houses...

only nature should paint

trees and rocks.

FOREST SERVICE
RAL TECHNICAL REPORT NC-44

Thirty Years of Soil and Water esearch by the Forest Service in Wisconsin's Driftless Area

A History and Annotated Bibliography

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1978

THIRTY YEARS OF SOIL AND WATER RESEARCH BY THE FOREST SERVICE IN WISCONSIN'S DRIFTLESS AREA—A HISTORY AND ANNOTATED BIBLIOGRAPHY

Richard S. Sartz, *formerly Principal Hydrologist, now retired, LaCrosse, Wisconsin*

Research on the causes and prevention of floods nd erosion in the upper Mississippi Valley's nglaciated region ("Driftless Area") was begun y the North Central (then Lake States) Forest xperiment Station in the late 1920's. This earlier rogram ended with the outbreak of World War II. second program was begun in 1958. Now, 17 ears later, we have finally answered the uestions that were first asked nearly 50 years go.

This history and bibliography lists and annotes the papers published during both programs d summarizes the content of unpublished apers in somewhat more detail. The papers are sted chronologically within subject matter cateories. Some earlier work not published at the me was published as part of the second program at began in 1958. To retain the historical quence in these cases, I based the chronological der on the *time of field work rather than on the me of publication.* Thus some authors and dates om the later program are included with the lists om the early program.

EARLY WORK BY BATES (1928-31)

The early work began with the appointment of arlos G. Bates to the fledgling staff of the Lake States Forest Experiment Station at St. Paul, Minnesota, in 1927. Before coming to the Lake States Station Bates had been in charge of Forest Service research in the Rocky Mountains, including the now famous Wagon Wheel Gap streamflow experiment in Colorado, the first controlled watershed experiment on the effect of forests on streamflow in the United States.

With 20 years of "forest influences" research already behind him when he joined the Station, Bates was one of a small handful of men who pioneered the new field of watershed management. These were the times of the dust bowl, of soil erosion on a massive scale, and the Nation was just beginning to take notice.

Mississippi River floods and mud, and the wholesale destruction of farms by river terrace erosion in Wisconsin's Driftless Area (fig. 1), served to focus Bates' attention on erosion sources and causes in this region. In 1929 he began a special study of erosion in southwestern Wisconsin and southeastern Minnesota. This work included stream sediment sampling, measuring runoff and erosion from different land uses (by means of "erosion traps") and, in cooperation with the Agricultural Experiment Station of the University of Wisconsin, the study of gully erosion and control methods. Some of the results of this work can be found in the publications listed at the end of the section.

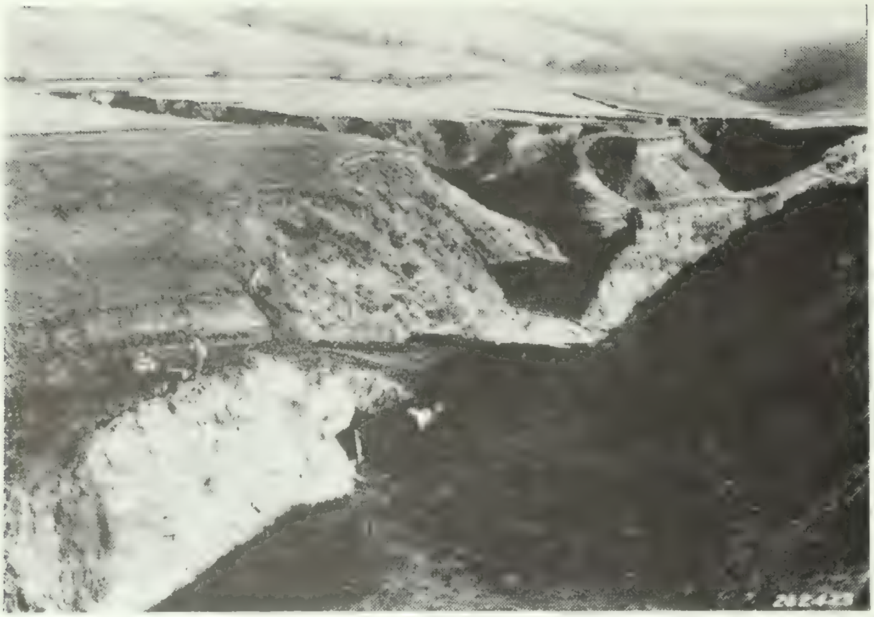

Figure 1.—*River terrace gully with "soil-saving dam", Buffalo County, Wisconsin, November 1931.*

This was also the time when flood *prevention* by better land management and other upstream measures was gaining ground as an alternative to the traditional engineer's concept of flood *control* by ever bigger and better engineering works. Bates was one of the leading protagonists in the controversy, as evident in this passage from reference (2):

"Since man became conservation-minded, the accepted method for river control has been to go to the sources, to correct watershed conditions as far as possible, and to erect check dams, straighten and rip-rap eroding channels, and otherwise improve the thousands of small feeder streams. Apparently such an undertaking is wholly beneath the dignity of the great modern engineers whose slogan is, 'Give me millions or give me death'."

Unchecked erosion was so widespread in the Driftless Area then that Bates felt that public acquisition of land was a necessity. Again from reference (2):

"...it is hardly reasonable to suppose that in a rich dairying region like southwestern Wisconsin, for example, land needed for fields or pastures will be devoted to the growing of trees, except through public acquisition of the land. That the public has a sufficient stake to justify this acquisition in critical areas, I think there can be no doubt."

Bates' assessment of the severity of the problem was based partly on his study of sediment movement in the area. The results were published in (1), pages 5-7, and in (3), pages 47-50.

Although most of the emphasis during these years was on river terrace gullies and stream sediment movement, Bates knew of the forest land gullies and was aware that they were caused by runoff from the "tableland" above. He mentioned this briefly in (1) and in the photo caption on page 2 of (3):

"This deposit of limestone fragments at the lower level is the result of cultivation on the table and above the present narrow belt of trees. Here is the beginning of a community problem."

Publications

(1) Bates, C. G. 1931. Chaining the father of waters. Am. For. 36(2):67-70, 106, 127.

Challenges a program that would spend
illions for flood control but nothing for flood
revention. Describes results of stream sediment
ampling in Driftless Area, and effect of land use:
iost silt comes from cultivated fields; forests
ield practically no runoff, and even less silt,
except as streams from tableland fields cut
ullies through them''. Describes silt and bedload
iovement in streams, and the need for improved
pstream practices.

2) Bates, C. G. 1933. Soil erosion in the
Iississippi Valley. J. For. 31:88-96.

Paper presented at the 13th annual convention
f the Mississippi Valley Association at St. Louis,
Iissouri.

Discusses in general terms the role of
egetation and terraces in runoff and erosion
ontrol, how gullies grow, and the relation of soil
rosion to stream siltation. Recommends a joint
ffort between land owners and governments,
cluding public acquisition of land, to control
rosion and floods. Discussion of gullies, soil-sav-
g dams, and mechanical means of checking
rosion alludes to conditions in the Driftless Area.

) Bates, C. G., and O.R. Zeasman. 1930. Soil
osion—a local and national problem. Wisconsin
gric. Exp. Stn. Res. Bull. 99, 100 p.

Discusses the natural balance between vegeta-
on, soil, and erosional processes, with examples
om southwestern Wisconsin. Describes the
riftless Area terrain and erosion problems, and
ves data from runoff and erosion traps and
ream silt sampling. Maximum runoff for
fferent covers were, in percent: forest, 2.8;
tural pasture, 7.2; hay, 17.7; cropland, 25.6;
eded pasture, 26.7. Describes recommended
osion control practices such as strip-cropping,
rraces, and soil-saving dams for gully control.

) U.S. Department of Agriculutre, Forest
rvice. 1931. The growth of a gully. U.S. Dep.
gric. For. Serv., Tech. Note 49, 1 p. Lake States
r. Exp. Stn., St. Paul, Minnesota.

Describes the gully process in the Driftless
ea. One large gully in Wisconsin advanced at a
te of 500 feet per year between 1923 and 1929.
the same time the many branches developed nearly 1,000 feet of smaller gullies. Maximum depth was 50 feet, and about 400,000 cubic yards of material washed away, destroying 25 acres of land.

THE EROSION EXPERIMENT STATION YEARS (1932-41)

In 1931, the U.S. Department of Agriculture in cooperation with the Wisconsin College of Agriculture established the Upper Mississippi Valley Erosion Experiment Station (''Erosion'' was later changed to ''Conservation'') on 160 acres of ridgeland near LaCrosse. Though primarily for cropland erosion research by the Soil Conservation Service (later to become ''Agricultural Research Service'') it was also a ''branch station'' for the Lake States Forest Experiment Station, first with Joseph H. Stoeckeler, then with Harold F. Scholz in charge of on-the-ground operations.

Unpublished Catchment Studies

The main activities centered around three small catchments in different land uses and a series of 10 large lysimeters. Runoff and soil loss along with other measurements and observations were monitored on both for a period of years. Other studies were carried on, both on and off Station land.

Sholz, Harold F. 1937. Erosion: Its relationship to woodlot managment and the use of critical slopes for pastures and tilled crops. Part I and Part II.

Neu, Robert G. 1940. Erosion: Its relationship to woodlot managment and the use of critical slopes for pastures and tilled crops. Part III.

Three small catchments were put under observation in 1933, and runoff and soil loss were continuously monitored through 1941 (fig. 2). All three sloped to the north and had similar soils. They were disignated A, B, and G. A (2.7 acres) was grazed forest, B (11.5 acres), ungrazed forest, and G (5.8 acres), grazed open. (''G'' was converted from second-growth forest in 1932 by clearcutting and burning and by ''closely supervised grazing''. This produced a heavy bluegrass sod.) The most complete published summary of the results is given in (8).

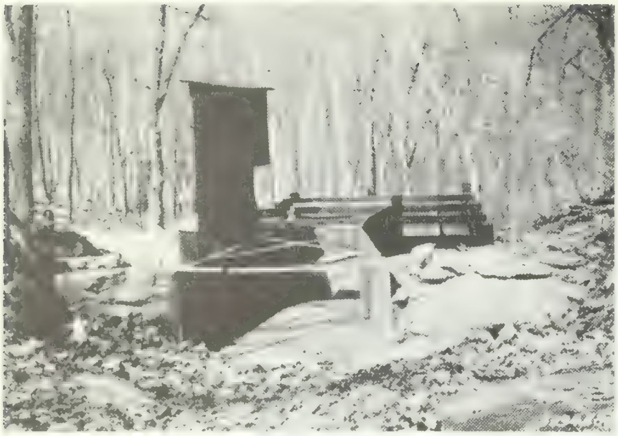

Figure 2.—*Parshall flume with instrument shelter and silt collecting box, Watershed "B", Upper Mississippi Valley Soil Erosion Station, 1936.*

Snow and frost depths were measured on all three catchments for 3 years and soil temperature (measured 42 inches below ground by thermometers suspended inside galvanized pipes), on the grazed open and ungrazed forest catchments for 4 years. The results are shown in tables 1 and 2. Neu made these comments:

Table 1.—*Maximum and minimum mean frost depth on grazed and ungrazed catchments, 1937-1939*

(In inches)

Year	Maximum[1]			Maximum mean[2]		
	Ungrazed	Grazed		Ungrazed	Grazed	
	forest	Forest	Open	forest	Forest	Open
1937	10	14	22	4	8	10
1938	15	22	21	8	14	17
1939	7	18	26	2	7	13
Average	11	18	23	5	10	13

[1]Greatest individual depth measured.
[2]Greatest mean depth of 10 sample points.

Table 2.—*Maximum summer and minimum winter temperatures at 42 inches depth in grazed open and ungrazed forest catchments*

(In F)

Year	Summer		Winter	
	Forest	Open	Forest	Open
1935-1936	58.0	62.5	37.0	36.0
1936-1937	59.0	64.0	36.5	35.5
1937-1938	59.0	65.0	36.5	33.5
1938-1939	58.0	62.0	37.0	36.5
Average	58.5	63.4	36.8	35.4

"The frozen soil in the ungrazed woodlot is loose and crumbly while it is hard and compacted in the pasture areas.

"On the basis of existing records it can be stated that very little runoff occurs from pasture and woodlot areas on north-facing slopes during the spring breakup unless the thawing weather is accompanied by precipitation in the form of rain."

The forage value of forest versus open pasture was also studied. Woodland grazing was universally practiced, and the researchers sought information that could be used to discourage the practice on economic grounds. Much effort went into determining dollar values from the costs of clearing, fencing, and other practices, all of which would be meaningless today. The more useful value of total cow-days per acre per year was also computed. The 7-year means were: forest pasture, 62; open pasture, 128. In terms of carrying capacity, 1 acre of open pasture was worth 2 of forest pasture.

Publications-catchment

(5) Bates, C. G. 1936. The forest influence on streamflow under divergent conditions. J. For. 34:957-969.

Compares runoff under forest conditions in the Driftless Area of Wisconsin with that from mountain watersheds in Colorado (the famous Wagon Wheel Gap Study). Forest cover prevents surface runoff in both places. Discusses results from experimental catchments at LaCrosse. Analyzes the effect of land use on the flooding of Gilmore Creek, a small Driftless Area watershed in Minnesota.

(6) Bates, C. G. 1937. Controlling mad waters. Am. For. 43(6):278-281, 300, 321-322.

Discusses the Ohio River floods of January-February 1937, and the probable effects of upstream and downstream programs on future floods. Quotes data from catchment study at La Crosse: the ungrazed forested catchment produced only 0.3 inches of runoff from 90 inches of rain over a 3-year period, including 0.03 inches from 6 inches of rain in a 6-day period.

(7) Bates, C. G. 1938. Reforestation and flood control. J. For. 36:1073-1079.

(Published version of a talk presented at a joint meeting of the Woodlands Section of the Canadian Pulp and Paper Association, the Canadian Society of Forest Engineers, the Association of Forest Engineers of the Province of Quebec, and the Society of American Foresters held in connection with the One Hundred Second Meeting of the American Association for the Advancement of Science, Quebec, Canada, June 27-30, 1938.)

Deals with the flood control controversy—upstream vs. downstream control and what happens to infiltrated water, based on data from The Upper Mississippi Valley Erosion Experiment Station at La Crosse. Gives an illustration from the Root River, in Minnesota's Driftless Area.

(8) Hays, O.E., A. G. McCall, and F. G. Bell. 1949. Investigations in erosion control and the reclamation of eroded land at The Upper Mississippi Valley Conservation Experiment Station near LaCrosse, Wisconsin, 1933-1943. U.S. Dep. Agric., Tech. Bull. 973, 87 p.

Summarizes 10 years of research by the Soil Conservation Service on developing practices to control runoff and erosion on agricultural land in the Driftless Area. Includes the results from a study by the Lake States Forest Experiment Station of runoff from three small catchments for the period 1935-1941. Annual runoff (in percent of rainfall) was 1.16 for grazed forest and 0.35 for open land pasture. Soil losses (in tons per acre) were 0.14 for grazed forest and 0.05 for open land pasture. Comparable values for strip-cropped land were 7.32 percent and 2.66 tons. The amounts from ungrazed forest were insignificant.

(9) Scholz, H. F. 1938. The grazed wood lot—potential flood hazard and low-grade pasture. U.S. Dep. Agric. For. Serv., Tech. Note 142, 2 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

Grazed woods yield high runoff, and make poor pasture. During a period of severe floods, runoff from ungrazed woods was only 1/47 of that from pastured woods. Most of the year's water loss occurs during a few heavy rains. The data were from the experimental catchments at La Crosse.

(10) Scholz, H. F. 1937 and 1938. Forest cover keeps frost line at shallow depth. U.S. Dep. Agric. For. Serv., Tech. Note 130. Lake States For. Exp. Stn., St. Paul, Minnesota; and J. For. 36:78-79,

Frost in an open pasture penetrated to 10 inches, compared with 4 inches in an ungrazed woodlot. Frost in the pasture thawed from the top, but in the woodlot it thawed from the bottom. Frost disappeared from the woods two days earlier than from the pasture.

(11) Scholz, Harold F. 1951. The case against cows: 73 percent of Wisconsin farm woodlands subject to destructive pasturing. Tree Tips, p. 3-4; and Wisconsin Conserv. Bull. 16(12):3-5.

Gives some data from lysimeter and catchment studies at the La Crosse station from 1935 to 1938 to show how grazing can cause runoff and erosion.

Lysimeter Studies

The lysimeters (10 in all) were 20 feet long, 10 feet wide, and 4 feet deep, and were filled with undisturbed blocks of Fayette silt loam, a loess, plus an 8-inch layer of topsoil (fig. 3). They were operated from 1934 to 1942.

After a test period of about a year, treatments were established, and surface runoff, percolation, and soil loss were measured for 6 years. The treatments in six lysimeters were: hardwood seedlings with leaf mulch (two lysimeters); hardwood seedlings without leaf mulch; Scotch

Figure 3.—*Forest Service lysimeters during test period, Soil Erosion Station, 1934.*

pine seedlings with needle mulch; grass, and annual grain. The four other lysimeters had faulty percolation records because of broken pipes that went undetected at the time.

Few results were published at the time, partly because of some "impossible" results that were caused by the broken pipes. Bates was writing up the experiment when he died in July 1949, and the lysimeters were destroyed soon afterwards. I wrote the final report in 1963 (15).

Several supplementary studies were conducted in conjunction with the lysimeters, one of which was reported by Curtis in 1960 (13).

Publications-Lysimeters

(12) Bates, C. G. 1939. Symposium on "Forest Influence" studies and methodology. Chron. Bot. 5(2/3):184-188.

A writeup of a meeting of Forest Service watershed management (then called "forest influences") research workers, held at the San Dimas Experimental Forest, near Glendora, California, February 12-27, 1939. Gives some results from a La Crosse lysimeter study.

(13) Curtis, Willie R. 1960. Moisture storage by leaf litter. U.S. Dep. Agric. For. Serv., Tech. Note 577, 2 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Galvanized tanks were placed under boxes that contained 2 to 3 inches of hardwood or pine litter. The rain that filtered through the litter was measured by weighing the tanks. Both kinds of litter held about the same amount of rainfall: 34.2 percent for hardwoods; 33.2 percent for pine. The amount retained varied from 93.7 percent for small rains to 11 percent for rains greater than 1 inch.

(14) Sartz, Richard S. 1963. Water yield and soil loss from soil-block lysimeters planted to small trees and other crops, southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Pap. LS-6, 23 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

Surface runoff, percolation, and soil loss from lysimeters with different cover were measured for 6 years. Mulched tree seedlings and grass yielded little runoff and soil during the growing season, while unmulched seedlings and grain yielded large amounts. Differences by cover type were less distinct in the dormant season. Most of the percolation occurred during the dormant season. Annual variation was high in both seasons.

(15) Sartz, Richard S. 1964. Duration of percolation from a loess soil. U.S. Dep. Agric. For. Serv., Res. Note LS-40, 2 p. Lake States For. Exp. Stn. St. Paul, Minnesota.

Percolation from 4-foot deep lysimeters filled with loess soil was studied in southwestern Wisconsin. After complete soil moisture recharge, water percolated continuously for as long as 20 days without additional rainfall.

(16) Sartz, Richard S. 1965. Effect of forest litter on growth of hardwood seedlings. U.S. Dep. Agric. For. Serv., Res. Note LS-59, 2 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

Red and white oak and black walnut seedlings grew much faster on lysimeters that had a covering of leaf litter than on a lysimeter without litter. The third year after treatment the mulched black walnut, red oak, and white oak averaged 55 percent, 51 percent, and 40 percent taller, respectively. The faster growth probably resulted from more available moisture.

(17) Scholz, Harold F., and J. H. Stoeckeler. 1940. A lysimeter installation for studying forest influence problems. J. For. 38:256-260.

Describes construction of 10- by 20-foot lysimeters filled with loess soil blocks. The lysimeters were planted to small trees and other crops to study the effect of cover on runoff, percolation, and erosion.

(18) U.S. Department of Agriculture. 1937. Forest litter and gravelly soils—effective conservers of water. U.S. Dep. Agric. For. Serv., Tech. Note 124, 1 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

A lysimeter study showed that both forest litter and gravel mulch produced little surface runoff, and that during the summer, forest vegetation used most of the precipitation that fell. The data were from 1 year.

Unpublished Farm Woods Erosion Study

Scholz, Harold F. 1935-1936. Farm woods erosion study. (In Part II of "Erosion: Its relationship to woodlot management and the use of critical slopes for pastures and tilled crops")

A "Farmwoods-Erosion Study" was carried out in 1935-1936 under the direction of Harold F. Scholz in cooperation with the Forest Survey section. Its objective was to determine the *economic* value of the farm woods of the area to supplement the information on their *protective* value being determined from the Erosion Station studies.

The study consisted of an intensive survey of 3½ townships (3 in Wisconsin, ½ in Minnesota). Besides taking the normal forest survey data, the surveyors mapped open land uses, woodland grazing, and erosion features. The results were given only in unpublished documents and in the survey maps, one of which is shown in figure 4.

Although Bates had earlier pointed to ridgeland runoff as the cause of forest land gullies, their ubiquity along with extensive abuse of the forest through high-grading and uncontrolled grazing led some to believe that the gullies were caused by runoff from the forest. The survey reports shed new light on the issue:

"This study has covered to date 46,000 acres of severely eroded land. Every gully observed began at the concentration point of water running off of cultivated land, or a heavily grazed or poorly stocked woodlot.

"Frequently the head of a gully was found on the upper edge of a good woodlot, but there was evidence in each case that the concentration of water came from cultivated land on a field above.

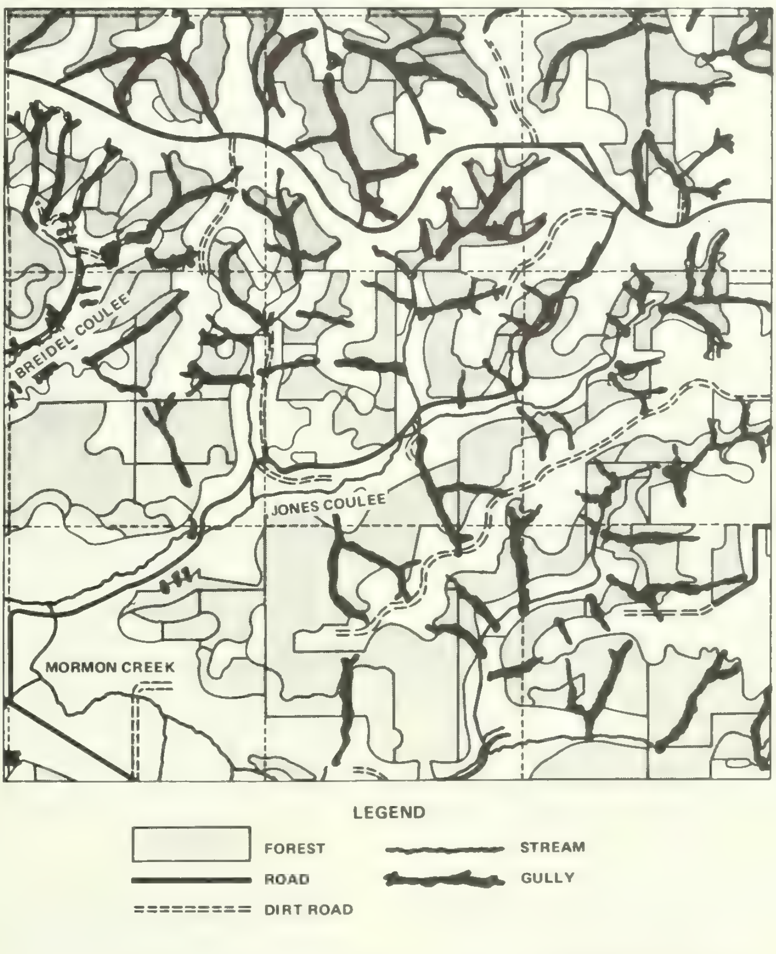

Figure 4.—*Land use and gully survey of sample township in LaCrosse County, Wisconsin, 1935.*

"...in 80 square miles that we have covered to date on this survey we have not found a single instance of erosion through forest except where it has been caused by open fields on the ridgetop."

Flood Control Surveys

In the Flood Control Act of June 22, 1936, the United States Congress officially recognized that watershed improvement measures should become an integral part of flood control planning. The act authorized the Department of Agriculture to conduct "flood control surveys"—field studies to determine to what extent floods could be prevented or reduced on individual watersheds through land use change and small engineering structures. The surveys were conducted jointly by the Soil Conservation and Forest Services.

Flood control surveys on the Kickapoo River in Wisconsin, and on the Whitewater River in Minnesota, both in the Driftless Area, were begun in 1938; and most of Bates' and Scholz's efforts were devoted to these surveys for the next few years.

THE COULEE EXPERIMENTAL FOREST AND FOREST WATERSHED LABORATORY YEARS (1958-1975)

After a 20-year lapse, watershed research was begun again in the Driftless Area when Congress appropriated money in 1958 for a Research Center at La Crosse. I was the first and only Project Leader. Creation of the center had been recommended by the Wisconsin Forestry Advisory Committee, and under a cooperative agreement with the (then) Wisconsin Conservation Department, the State agreed to provide a suitable outdoor laboratory for the research. The outgrowth was the Coulee Experimental Forest, a 2,900-acre area in La Crosse County typical of the land forms, soils, and land use in the unglaciated area. The forest was formally dedicated in June 1960.

The research unit was originally quartered in the La Crosse Federal Building, but in 1967 it moved to its own newly constructed laboratory building on land leased from the city (fig. 5).

Figure 5.—*Forest Watershed Laboratory, La-Crosse, project headquarters from 1967-1975.*

The primary mission of the new center was to study the effect of land use and steep land management on floods, soil erosion, and stream sedimentation—essentially a continuation of the earlier work but on a broader scale. A secondary mission during the early years of the project was to study the adaptability of various tree species and classes of planting stock to different sites. The information was sought to guide land owners in their tree-planting programs.

With its mission all but completed, the project was terminated and the laboratory building was turned over to the City of La Crosse at the end of 1975. The Department of Natural Resources continues to administer the state-owned Coulee Experimental Forest as a research area.

During its last few years, the La Crosse Field Unit began to work on land disposal of sewage effluent. This was an outlier of the primary effluent disposal project at East Lansing, Michigan. Field work on this mission was done at Fort McCoy under a cooperative agreement with the Department of the Army. The work was disbanded and the agreement terminated with the closing of the Forest Watershed Laboratory.

The publications that came from this era are given in the lists below, subdivided according to the primary subject matter. An easy-to-read summary of land managment recommendations is found in (32).

Unpublished—Soil Freezing

Harris, Alfred Ray. 1971. Effect of deciduous, coniferous, and abandoned field cover on the hydrologic properties and frost morphology of frozen soil. Ph.D. thesis. Univ. Minnesota, St. Paul, Minnesota.

During the 1969-70 freezing season the hydrologic properties and morphology of frozen Fayette silt loam soil under contiguous areas of natural deciduous forest, 25-year-old coniferous plantation, and 6-year-old abandoned field vegetation were studied.

The deciduous forest had the least frost, the conifer plantation, the most. All plots had concrete frost. Infiltration rates in the deciduous forest and abandoned field did not decrease significantly until late winter when snowmelt infiltrated and froze, blocking drainage pores. Rates in the conifer plantation were very low because of an ice layer that formed when snowmelt dripped from the canopy. Infiltration rate was not significantly correlated with bulk density, water content, air pore volume, or total pore volume, partly because of the large macro pore volume in the soil.

Bulk density reductions were greatest in the deciduous forest plots, and were greater for the surface soil layer than for the subsurface soil layer. Both bulk density and air pore volume were inversely correlated with water content.

Publications—Soil And Water

Land use effects on soil properties, runoff, and erosion:

(19) Curtis, Willie R. 1966. Forest zone helps minimize flooding in the Driftless Area. J. Soil Water Conserv. 21(3):101-102.

Forested slopes absorb rainfall runoff from upland fields, reducing water movement, soil erosion, and downstream flooding in southeastern Minnesota and southwestern Wisconsin.

(20) Curtis, Willie R. 1967. Simple practices along forest edge reduce upland runoff. J. Soil Water Conserv. 22(1):25-26.

The portion of upland runoff that reaches valley bottoms can be reduced by diversions and simple land treatments, such as logs along the contour in natural forest and detention ponds in series installed along the field-forest border.

(21) Knighton, M. Dean. 1970. Forest floor characteristics in southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Note NC-102, 2 p.m North Cent. For. Exp. Stn., St. Paul, Minnesota.

Percent slope, aspect, topographic position, and crown closure did not influence forest floor depth. However, a decrease in forest floor depth and an increase in soil compaction were found on currently grazed slopes. Cessation of grazing resulted in rapid recovery.

(22) Knighton, M. Dean. 1977. Soil changes after hay meadow abandonment in southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Pap. NC-146, 6 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Soil ameliorating processes that accompany agricultural abandonment of alfalfa hay meadows were studied for 3 years. Average bulk density decreased from 1.28 to 1.10 in 2 years and then stabilized. As expected, total porosity increased; most of the change occured in the large pore fraction. Organic carbon increased from 1.60 to 2.20 percent during the 3 years. Infiltration rate increased 100 percent over that of adjacent active hay meadows. Earthworm activity was considered to be the primary cause of the changes.

(23) Knighton, M. Dean. 1977. Hydrologic response and nutrient concentrations following spring burns in an oak-hickory forest. Soil Sci. Soc. Am. J. 41:627-632.

Three annual spring burns in southwestern Wisconsin did not increase overland flow or soil loss on sloping (25 to 50 percent) plots. However, no particularly severe storms occurred during the study. The protective characteristics of the ground cover were not altered, and shrubs sprouted vigorously. Bulk density, total pore volume, organic carbon content, and intrinsic permeability

of the mineral soil were unaffected, but mobility of nitrate-nitrite nitrogen and phosphate increased with the number of burns. Calcium and magnesium mobility was increased but potassium and sodium mobility was not. Nutrient loss by leaching was less than the input from precipitation.

(24) Sartz, Richard S. 1959. Forests and water: A tale of two watersheds. Wisconsin Acad. Rev. 6:55-58.

How forests minimize floods and erosion is told by describing what happens when both a forested and a bare watershed are hit by a heavy rain.

(25) Sartz, Richard S. 1960. Forests and erosion in the Driftless Area. Wisconsin Conserv. Bull. 25(3):21-24.

Explains how geologic erosion shaped the land forms of the Driftless Area and how man has triggered a new cycle of erosion through overdevelopment of the land for agriculture. A study of wooded watersheds showed no accelerated erosion.

(26) Sartz, Richard S. 1961. The forest-land gully in the Driftless Area—natural or man-caused? U.S. Dep. Agric. For. Serv., Tech. Note 612, 2 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

To test the theory that the forest-land gully—a common feature of the Driftless Area—has resulted from ridgetop farming, a survey of 40 completely forested drainages was made to check for gullies or other signs of surface flow. Not a single gully or eroded channel was found. Other evidence also strongly suggests that gully erosion was not a feature of the natural landscape.

(27) Sartz, Richard S. 1961. Comparison of bulk density of soil in abandoned land and forest land. U.S. Dep. Agric. For. Serv., Tech. Note 601, 2 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

Soil core samples taken in the same soil type (Dubuque silt loam) under two different land uses showed the effects of land clearing and cultivation on bulk density of the soil. In the natural soil profile under an oak-hickory stand, bulk density in the upper 3 inches was 0.70. In the open land profile it was 1.08. Bulk density in the 3- to 6-inch layer was slightly higher in the forest than in the open, but from 6 to 24 inches there was little difference.

(28) Sartz, Richard S. 1965. Forestry research to benefit trout? Wisconsin Conserv. Bull. 30(2):20-21.

This popular-style article explains how land use, through its effect on infiltration and soil freezing, can influence flood runoff and the base flow of streams, both key factors in trout stream management. By better defining the effects of different tree species and cutting patterns, forestry research can benefit trout.

(29) Sartz, Richard S. 1969. Effect of watershed cover on overland flow from a major storm in southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Note NC-82, 4 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Both total and peak flows from a 3-hour, 4-inch rain were strongly affected by land cover. Peak flows ranged from 2.42 inches per hour for alfalfa meadow to 0.010 inches per hour for undisturbed forest. The timing of flow on open land and forested catchments was surprisingly similar.

(30) Sartz, Richard S. 1970. Effect of land use on the hydrology of small watersheds in southwestern Wisconsin. Int. Assoc. Sci. Hydrol., Symposium on the results of research on representative and experimental basins. IASH-Unesco 96:286-295. (Wellington, New Zealand, Dec. 1970).

Forest watersheds produced flow only after heavy rains, and the amounts of flow and peak rates were low compared with those from openland watersheds. Peak flow rates from a major storm ranged from 64 millimeters per hour for tilled land to no flow for undisturbed forest. Peak rates from tilled land averaged 2.5 times those from meadow, and peak rates from meadow 1.4 times those from an abandoned field. Sediment discharge was low for forest, abandoned field, and meadow, but high for tilled land and heavily grazed pasture.

(31) Sartz, Richard S. 1971. Storm flow from dual-use watersheds in southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Pap. NC-69, 7 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Compares storm flow from upland fields with outflow at the bottom of wooded slopes below. In general, larger upland flows produced larger lower station flows. Lower station flow as a percentage of upland runoff for large storms ranged from 56 to 94.

(32) Sartz, Richard S. 1975. Controlling runoff in the Driftless Area. J. Soil Water Conserv. 30:92-93.

Tilled cropland is the major source of floods and stream sediment in the unglaciated region; thus, reducing the cropland area in a watershed is an effective flood prevention measure. Hayland and pastureland produce much less runoff than tilled land, and little sediment. Simply taking land out of active cultivation greatly reduces the amount of water that flows from sloping fields. Runoff from forest land is minimal, regardless of its condition.

(33) Sartz, Richard S. 1976. Sediment yield from steep lands in the Driftless Area. *In* third Federal Interagency sedimentation Conf. Proc., Denver, Colorado, March 22-26, 1976.

Substantial amounts of sediment were discharged only from cultivated or heavily grazed catchments. The greatest amounts—sometimes exceeding 200,000 parts per million—came from tilled cropland in early stages of crop development. Ungrazed forest and prairie yield no significant amounts of runoff or sediment, regardless of slope steepness, unless they intercept water from overlying fields. However, field runoff can carve huge gullies on forested slopes that lie below cultivated uplands. Thus, the forested slopes of the area have been a major sediment source from gully erosion since the time of settlement.

(34) Sartz, Richard S. 1976. Effect of plantation establishment on soil and soil water in southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Pap. NC-127, 8 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Changes in litter weight, soil bulk density, soil nitrogen and organic carbon contents, soil water depletion, and snowpack accumulation were evaluated over 14 years of plantation growth on three different sites. The species studied were white and red pines, white spruce, and European larch, along with unplanted controls.

(35) Sartz, Richard S. [In press.] Soil erosion in the Lake States Driftless Area—a historical perspective. Transactions, Wisconsin Academy of Sci., Arts, and Letters.

The history of both geologic and man-caused erosion in the upper Mississippi Valley's "Driftless Area" and man's sometimes futile control efforts are presented in this popular-style article, with eight illustrations.

(36) Sartz, Richard S., Willie R. Curtis, and David N. Tolsted. 1977. Hydrology of small watersheds in Wisconsin's Driftless Area. Water Resour. Res. 13(3):524-530.

Steep, unglaciated terrain, and a peculiar land use pattern give the Upper Mississippi Valley's unglaciated region a distinctive hydrology. Catchments smaller than 250 hectares normally have no perennial streams, but may have many springs that flow for short distances and then reenter the ground. Land use greatly influences the surface hydrology. Tilled cropland is the principal source of flood runoff and stream sediment. Runoff from forest land is minimal regardless of its slope or condition. The ground water picture is complex, with perched water bodies and dry pockets intermixed with water tables that rise and fall in rapid response to rainfall and snowmelt and in close synchronization with springflow. Snowmelt produces a distinctive diurnal pattern of both overland flow and ground water rise, sometimes in midwinter. Larger catchments responded to both rainfall and snowmelt much the same as smaller experimental catchments.

(37) Sartz, Richard S., and Alfred Ray Harris. 1972. Growth and hydrologic influence of European larch and red pine 10 years after planting. U.S. Dep. Agric. For. Serv., Res. Note NC-144, 4 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Ten years after planting, European larch and red pine diameters averaged 11.2 and 9.6 cm, and heights, 9.7 and 5.1 m. Litter on the larch plots was twice as heavy as on the pine and unplanted control plots. The amount of water depleted by the two species was about the same, and it was about twice the amount depleted by a grass and weed cover.

(38) Sartz, Richard S., and David N. Tolsted. 1974. Larch litter removal has no significant effect on runoff. U.S. Dep. Agric. For. Serv., Res. Note NC-163, 2 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Runoff was measured on paired litter-removed, litter-left plots in an 11-year-old European larch plantation. On five of the six pairs of plots, the plot with the litter left intact yielded more runoff. However, the differences were neither statistically nor hydrologically significant.

(39) Sartz, Richard S., and David N. Tolsted. 1974. Effect of grazing on runoff from two small watersheds in southwestern Wisconsin. Water Resour. Res. 10:354-356.

Runoff behavior of two small open pasture catchments was similar when both were grazed, but by the third year after cessation of grazing on one, its runoff had dropped sharply. The ungrazed /grazed ratio for mean total flow had dropped from 1.17 to 0.10 and for mean peak flow from 0.82 to 0.03. After 3 years without grazing a heavy mat of bluegrass blanketed the ground, and soil bulk density was significantly lower.

(40) Stoeckeler, J.H. 1959. Trampling by livestock drastically reduces infiltration rate of soil in oak and pine woods in southwestern Wisconsin. U.S Dep. Agric. For. Serv., Tech. Note 556, 2 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

Livestock trampling reduced infiltration by 93 percent as measured by 3-inch cylinders. (See also (41) and (44).

Soil freezing:

(41) Harris, Alfred R. 1972. Infiltration rate as affected by soil freezing under three cover types. Soil Sci. Soc. Am. Proc. 36:489-492.

Infiltration rates on abandoned land may be as high as on deciduous forest. Infiltration was affected mainly by the number and orientation of connected macropores and by the degree of blockage of the larger drainage channels with ice. Ice crust formation may be a problem caused by tight conifer canopies and can contribute to runoff.

(42) Sartz, Richard S. 1969.Soil water movement as affected by deep freezing. Soil Sci. Soc. Am Proc. 33:333-337.

Changes in soil water content took place throughout much of the frost season, even with deep soil frost. Water may infiltrate and percolate through more than 60 cm of hard-frozen ground. However, frozen ground did impede percolation, causing a buildup of water in the frozen zone during spring melt.

(43) Sartz, Richard S. 1970. Natural freezing and thawing in a silt and a sand. Soil Sci. 109:319-323.

Although the two soils began to freeze at the same time, frost penetrated faster and deeper and thawed sooner in the sandy soil. During the spring thaw, frost persisted in the silt 3 weeks longer than in the sand. The sand began thawing at the surface 7 days before the silt, and it was completely thawed 15 days later.

(44) Sartz, Richard S. 1973. Effect of forest cover removed on depth of soil freezing and overland flow. Soil Sci. Soc. Am. Proc. 37:774-777.

Removing only the litter and removing all the vegetation from hardwood forest plots increased both soil freezing depth and overland flow. Removing only the woody vegetation decreased both. Frost depth means in a year of deep frost were 6 and 11 cm on the woody vegetation removed and undisturbed plots, and 19 and 35 cm on the all vegetation removed and litter-removed plots. Overland flow ranged from less than 1 cm on the woody vegetation-removed plots to more than 7 cm on the all vegetation- and litter-removed plots.

(45) Sartz, Richard S. 1973. Snow and frost depths on north and south slopes. U.S. Dep. Agric. For. Serv., Res. Note NC-157, 2 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Aspect affects soil frost depth by influencing the amount of solar radiation received at the ground or snow surface. Depending on the conditions, frost can be of equal depth on north and south slopes, deeper on north slopes, or deeper on south slopes. Data illustrate all three conditions. [See also (80).]

Springflow and ground water:

(46) Curtis, Willie R. 1963. Flow characteristics of two types of springs in southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Note LS-1, 2 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

Springs on the Coulee Experimental Forest are found at two levels—approximately 900 and 1,000 feet above sea level. Flow from the 1,000-foot springs is practically constant the year round, while flow from the lower level springs varies by season, month, and day in relation to climatic variables. A hydrograph of daily discharge for 1961 for each level of spring is presented.

(47) Curtis, Willie R. 1966. Response of springflow to some climatic variables in southwestern Wisconsin. Water Resour. Res. 2:311-314.

Springflow responds to barometric pressure in southwestern Wisconsin, and it fluctuates much as does ground water in response to precipitation and soil moisture.

(48) Sartz, Richard S. 1967. Winter thaws can raise ground water levels in Driftless Area. U.S. Dep. Agric. For. Serv., Res. Note NC-35, 2 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Springflow and ground water levels both rose with winter thaws, even when the ground was frozen. A high soil water content suggests that water moved to the water table through a continuous column of soil water rather than as a wetting front.

(49) Stoeckeler, Joseph H., and Glenn J. Voskuil. 1959. Water temperature reduction in shortened spring channels of southwestern Wisconsin trout streams. Am. Fisheries Soc. Trans. 88:286-288.

Late afternoon summer water temperature at the mouth of a spring channel on a trout stream near La Crosse in southwestern Wisconsin were reduced by 10 degrees to 11 degrees F. by shortening the channel by 67 percent and routing the water through a willow-shaded location. [See also (36).]

Evapotranspiration:

(50) Sartz, Richard S. 1972. Anomalies and sampling variation in forest soil water measurement by the neutron method. Soil Sci. Soc. Am. Proc. 36:148-153.

Sampling errors were determined for neutron meter measurements of soil water content in a heterogeneous forest soil. Variance at individual 30-cm depths on uncut plots increased with depth at a high water content but was uniform at a low water content. Changes over a period of time were more variable than at a single point in time. Soil depth differences contributed substantially to the variance of total storage changes.

(51) Sartz, Richard S. 1972. Soil water depletion by a hardwood forest in southwestern Wisconsin. Soil Sci. Soc. Am. Proc. 36:961-964.

Water depletion by uncut forest began early in the growing season at all depths measured and continued at a nearly constant rate until leaf fall. Seasonal depletion in a 1.5 m soil mantle averaged 188 mm on uncut plots, 87 mm on clearcut plots, and 57 mm on plots without vegetation. The amount of depletion increased with mantle depth; thus cutting had a greater water-saving effect on deeper soils.

(52) Sartz, Richard S., and M. Dean Knighton. 1978. Soil water depletion after four years of forest regrowth in southwestern Wisconsin. U.S. Dep. Agric. For. Serv. Res. Note NC-230, 3 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The effect of cutting on water depletion from a 150-cm soil mantle does not appear to have diminished by the 7th year after the trees were cut. Mean seasonal depletion was 41, 64, and 146 mm for all-vegetation-removed, woody-vegetation-removed, and uncut treatments, respectively. After 4 years of regrowth, the original bare and clearcut treatments depleted only 21 and 35 percent as much water as the uncut forest.

(53) Stoeckeler, J.H., and Willie R. Curtis. 1960. Soil moisture regime in southwestern Wisconsin as affected by aspect and forest type. J. For. 58:892-896.

Gives results of soil moisture on a transect across a valley, from ridge to ridge, showing markedly better moisture conditions on north- versus south-facing slopes. Tree growth in pine plantations was 3.5 times better than in oak on south-facing slopes. [See also (34) and (37).]

Climate:

(54) Sartz, Richard S. 1966. Rainfall distribution over dissected terrain in southwestern Wisconsin. Water Resour. Res. 2(4):803-809.

Dissected terrain of southwestern Wisconsin has only a small effect on annual point rainfall; the variance in rainfall within such an area probably results more from normal storm variation.

(55) Sartz, Richard S. 1967. Annual soil temperature wave at four depths in southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Note NC-32, 2 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

The annual soil temperature wave measured on a southeast slope in southwestern Wisconsin followed the air temperature wave at all depths.

(56) Sartz, Richard S. 1972. Effect of topography on microclimate in southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Pap. NC-74, 6 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Ridge and coulee terrain has little effect on point rainfall, but snowpack accumulation is affected by degree of slope and aspect. North slopes accumulate about 50 percent more snow. Soil water depletion is little affected by aspect. South slopes receive more insolation than north slopes, but temperature differences are slight and may result more from wind differences than from aspect. Air drainage has a significant effect on nighttime air temperatures in coulee bottoms.

(57) Stoeckeler, Joseph H. 1963. Springtime frost frequency near LaCrosse, Wisconsin, as affected by topographic position, and its relation to potential reforestation problems. J. For. 61:379-381.

Frosts of 30° F or less were eight times more abundant in a 2-year period in a cove at elevation of 920 feet above sea level than in a nearby ridgetop at 1,250 feet elevation.

Publications—Reforestation

(58) Knighton, M. Dean. 1970. Simazine ma stunt young European larch. Tree Plant. Note 21(2):17.

Fall spraying young European larch wit Simazine reduced height growth by 14 percen and increased mortality 2 percent the year afte spraying.

(59) Knighton, M. Dean. 1972. Effects of groun preparation on planted red pine in southwester Wisconsin. U.S. Dep. Agric. For. Serv., Res. Not NC-134, 2 p. North Cent. For. Exp. Stn., St. Pau Minnesota.

After 9 years, 3-0 red pines planted by machin and by hand in single plowed furrows had 3 percent more survival than trees hand planted i scalps. Planting method did not affect survival o 2-1 transplants. Height growth was 18 percen greater for machine and single-furrow plante trees than for hand planted trees. Bench terrace and double furrows gave intermediate values.

(60) Sartz, Richard S. 1965. Effect of forest litte on growth of hardwood seedlings. U.S. Dep Agric. For. Serv., Res. Note LS-59, 2 p. Lak States For. Exp. Stn., St. Paul, Minnesota.

Red and white oak and black walnut seedling grew much faster on lysimeters that had covering of leaf litter than on a lysimeter withou litter. The third year after treatment the mulche black walnut, red oak, and white oak averaged 5 percent, 51 percent, and 40 percent talle respectively. The faster growth probably resulte from a greater supply of available moisture.

(61) Sartz, Richard S. 1968. Hail can seriousl damage eastern white pine. J. For. 66:353.

Hail seriously damaged a seventh-year whit pine plantation by riddling the bark on main stem and lateral branches. Red pine, white and Norwa spruces, and European larch on the same sit were not damaged.

|2) Sartz, Richard S. 1970. Mouse damage in)ung plantations in southwestern Wisconsin. J. or. 68:88-89.

Meadow voles caused serious losses in old-field lantings of Austrian and Scotch pine, Norway oruce, and European larch. White pine was not eavily attacked, and white spruce was passed up ompletely. No damage or other mouse signs were und on south aspect plantings.

3) Stoeckeler, J.H. 1962. Planting research on ie Coulee Forest. Wisconsin Conserv. Bull. 7(1):10-11.

Describes a new program of reforestation esearch started in spring 1961 on the Coulee xperimental Forest near La Crosse, Wisconsin, cooperation with the Wisconsin Conservation epartment. Planting trials the first year with 5,000 trees involved 11 species, 4 age classes, nd 2 transpiration retardants planted on both ool and hot aspects of microsite.

54) Stoeckeler, J.H. 1962. Angle-dozer used for ree planting. J Soil Water Conserv. 17:178-179.

A small angle-dozer was used with good conomy in making 30.5 miles of level, narrow ench terraces at an average cost of $12.20 per nile, or $12.57 per acre for a calculated 8-foot pacing between rows. The study was made in illy terrain in southwestern Wisconsin with lopes up to 32 percent. Advantages and mitations of the method are discussed.

65) Stoeckeler, Joseph H. 1963. Ground prepara-ion costs and first-year survival of planted red ine in southwestern Wisconsin. U.S. Dep. Agric. For. Serv., Res. Note LS-28, 4 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

A comparison is made in field survival and costs or 3-0 and 2-1 red pine planted in five different ypes of ground preparation; that is, bench erraces, single furrows, double furrow, Lowther nachine, and scalps.

66) Stoeckeler, Joseph H. 1963. Early survival of lanted trees in southwestern Wisconsin, by pecies, age classes, and site factors. U.S. Dep. Agric. For. Serv., Res. Note LS-27, 4 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

Survivals are given for first and second years for all species combined, and for the commonly planted 2-0, 3-0, and 2-1 red pine on 10 field reforestation plots of various aspects, soils, and topographic positions. Species and age-class recommendations are made for six classes of sites.

(67) Stoeckeler, J.H. 1964. Two-year results of direct-seeded black walnut in a cove on the Coulee Experimental Forest, LaCrosse, Wisconsin. Tree Plant. Notes 67:12-13.

A second-year stocking of 85 percent and a germination of 49 percent were achieved in directly field seeding three seeds per seed spot in conventional 12-inch-wide furrows.

(68) Stoeckeler, Joseph H. 1965. Spring frost damage in young forest plantings near LaCrosse, Wisconsin. J. For. 63:12-14, and Am. Christmas Tree Growers' J. 9(2):36, 38-40.

Observations of effects of spring freezing of May 22-23, 1963, on 13 tree species in second- and third-year plantations near La Crosse, Wisconsin, indicate the following sensitivity to frost injury: sensitive—Norway spruce, white spruce, European larch; slightly sensitive—Austrian pine; not sensitive—jack, ponderosa, red, Scotch, and white pines and eastern redcedar. Some variation was noted in frost damage by altitude.

(69) Stoeckeler, J. H. 1966. Hexadecanol applied to foliage improves early field survival of pine planting on a droughty site. J. For. 64:200-201.

Hexadecanol, a saturated, fatty alcohol, reduced the drought loss of 3-0 red pine planted on a steep, dry, windswept hillside in Wisconsin.

(70) Stoeckeler, J. H. 1966. Trees for the Coulee Region. Wisconsin Conserv. Bull. 31(1):14-16.

Pinpoints the species responding the best of 13 planted in Wisconsin's Coulee Region according to nursery-stockage class, ground preparation, aspect, soil condition, ground cover, and topographic position.

Publications—Research Instruments and Techniques

(71) Curtis, Willie R. 1960. An automatic trigger device for use on FW-1 water level recorders. J. For. 58:819-821.

Explains construction and operation of a time-saving trigger device used in conjunction with water-level recording on ephemeral streams. During no-flow periods the clock is kept from running by application of back pressure. When flow occurs, movement of float activates release mechanism and clock begins to run.

(72) Curtis, Willie R. 1961. An inexpensive water-level point gage. U.S. Dep. Agric. For. Serv., Tech. Note 613, 2 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

Materials and methods of construction of an inexpensive water level point gage are described. The gage is for use in conjunction with streamflow recording stations. Three photographs show general view and specific details of construction.

(73) Curtis, Willie R. 1963. Device for automatically starting a recording rain gage when rainfall begins. U.S. Dep. Agric. For. Serv., Res. Note LS-3, 3 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

The device described allows a recording rain gage to operate only after rainfall begins. Only a few drops of water are necessary to trigger the mechanism. Construction detail is shown in three photos, and the needed materials are listed.

(74) Curtis, Willie R. 1963. Tool for editing analog-to-digital tapes. J. Soil Water Conserv. 17:254.

Describes details of construction and use of a tool that aids in the editing and computing of punched tape obtained with analog-to-digital recorders.

(75) Curtis, Willie R., and David N. Tolsted. 1967. Chart holder uses old typewriter parts. Agric. Eng. 48(3):154-155.

Describes how to make and use a chart holder that increases accuracy and reduces calculation time when computing runoff volumes by the Copley method. Most of the parts can be salvaged from an old typewriter.

(76) Hansen, Edward A., and Alfred Ray Harris 1974. A ground water profile sampler. Water Resour. Res. 10(2):375.

A ground water profile sampler was developed for obtaining water samples at predetermined depths. This permits determining the gradients of contaminants in a ground water system.

(77) Hansen, Edward A., and Alfred Ray Harris 1975. Validity of soil-water samples collected with porous ceramic cups. Soil Sci. Soc. Am. Proc 39:528-536.

Laboratory and field tests were made to determine if porous ceramic cups collect representative samples of nitrate and phosphate from soil water. Sources of sample bias were sorption leaching, diffusion, and screening of ions by the cup walls. Sample variability was strongly influenced by sampler intake rate, plugging, sampler depth, and type of vacuum system. The demonstrated variability and unknown bias make interpretation of sampler data difficult.

(78) Harris, Alfred Ray. 1970. Direct reading frost gage is reliable, inexpensive. U.S. Dep. Agric For. Serv., Res. Note NC-89, 2 p. North Cent. For Exp. Stn., St. Paul, Minnesota.

A tube-type gage is economical, easy to make and is a reliable indicator of frost depth. Gage readings were within 5 cm of indicated true frost depth 95 percent of the time.

(79) Harris, Alfred Ray. 1975. Evaluation of several methods of applying sewage effluent to forested areas in the winter. Agron. Abstracts 67th Annual Meeting Am. Soc. Agron., p. 166 (Knoxville, Tennessee, Aug. 24-30, 1975.)

Sewage effluent was applied by surface subsurface, and sprinkler systems to a forested area for two winters at Fort McCoy, Wisconsin Water distribution in the frozen soil was generally poor for all the systems. Wet spots were interspersed with dry spots in the frozen soil indicating that water did not distribute evenly but merely enriched areas close to conducting

channels. Although substantial effluent infiltrated the frozen soil with each method, the feasibility of wintertime irrigation in forested areas is still uncertain because of site disturbance and poor renovation of effluent.

(80) Harris, Alfred Ray, and Edward A. Hansen. 1975. A new ceramic cup soil-water sampler. Soil Sci. Soc. Am. Proc. 39:157-158.

A newly designed soil-water sampler utilizing a miniature porous ceramic cup is suitable for either collecting large samples or for micro techniques. It eliminates sample transfer in the field and contamination from water channeling along sampler, and can be enclosed to discourage vandalism. It also permits immediate preservation of the collected sample.

(81) Knighton, M. Dean. 1978. Estimating infiltration from soil properties for a loessal silt loam. U.S. Dep. Agric. For. Serv., Res. Note NC-233, 4 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

An infiltration model for a loessal silt loam in southwestern Wisconsin was developed and tested. The model depends on soil physical properties for estimating infiltration. The properties showing the greatest significance were organic carbon content, total pore space, and moisture content. Bulk density and large pore space also proved to be significant. The model adequately predicted final infiltration rates but was weaker with respect to initial rates on an abandoned field and a conifer plantation. When tested against measured infiltration rates in an undisturbed oak-hickory woods the model proved to be inadequate.

(82) Sartz, Richard S. 1962. Field transport for the neutron soil-moisture meter. J. Soil. Water Conserv. 17:27.

A three-wheeled buggy for transporting a Nuclear-Chicago neutron-scattering soil-moisture meter is described and illustrated. It is made from the front half of a girl's bicycle frame, a rear axle with heavy-duty bicycle tires, and a plywood carriage. It can be used over rough terrain. Cost was $64.

(83) Sartz, Richard S. 1967. A test of three indirect methods of measuring depth of frost. Soil Sci. 104(4):273-278.

A modified frost penetrometer, which was found to be fast and accurate, was used as a check on indirect methods of measuring depth of concrete frost penetration. Resistance block determinations agreed well with the penetrometer measurements. The Soiltest frostmeter was found to be unreliable as a scientific instrument.

(84) Sartz, Richard S. 1969. Interpreting neutron probe readings in frozen soil. U.S. Dep. Agric. For. Serv., Res. Note NC-77, 4 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Temperature was not important, but the effect of vertical resolution is particularly important in frozen soil because of water and ice buildup on and near the ground surface. The possibility of both downward and upward movement of water complicates the interpretation of neutron probe readings in frozen soil.

(85) Sartz, Richard S., and Willie R. Curtis. 1961. Field calibration of a neutron-scattering soil moisture meter. U.S. Dep. Agric. For. Serv., Stn. Pap. 91, 15 p. Lake States For. Exp. Stn., St. Paul, Minnesota.

A method of calibrating the Nuclear-Chicago neutron-scattering soil-moisture depth probe by gravimetric sampling is explained. Soil moisture contents as determined from the manufacturer's calibration curve were found to be too high at low moisture levels and too low at high moisture levels. Correction factors for shallow readings are given for the particular instrument used.

(86) Sartz, Richard S., and Willie R. Curtis. 1967. Simple sediment sampler for flumes. Agric. Eng. 48(4):224.

A method of automatically collecting suspended sediment samples from flumes is described and illustrated.

Publications—Miscellaneous

(87) Dils, Robert E. 1957. Watershed management research needs in the forests of the Lake

States. Michigan State Univ. Agric. Exp. Stn. Spec. Bull. 416, 35 p.

Provides a survey of watershed management research needs in the northern forest area and the Driftless Area of the Lake States. Describes the water resources and requirements and the problems in watershed management. Background information includes climate, topography and geology, soils, and land use.

(88) Sartz, Richard S. 1962. The Coulee Experimental Forest—A new field laboratory for southwestern Wisconsin. Wisconsin Acad. Review 9(1):1-5.

A popular-style article on research on the Forest and how the Forest came into being.

(89) Sartz, Richard S. 1977. Carlos G. Bates, maverick Forest Service Scientist. J. For. Hist. 21(1):31-39.

Recounts the working life of C.G. Bates, from the famous Wagon Wheel Gap effect-of-forest-on-streamflow study to the Great Plains shelterbelts, his study of floods and erosion in the Driftless Area, and his taking on the dam-builders in the Mississippi River's Flood Control Controversy.

(90) Weitzman, Sidney. 1957. Needed—a forest research program for southwest Wisconsin. Wisconsin Conserv. Bull. 22(3):28-33.

Describes the condition of the forests in southwest Wisconsin with respect to both timber production and watershed protection. Discusses the problems and conflicts that brought about existing conditions. Outlines the research program needed to solve current problems.

LIST OF PERSONNEL

Full-time personnel associated with the research during the periods reported here are listed below, along with their working titles and years of tenure.

Station Directors

Raphael Zon	1928-44
Elwood L. Demmon	1944-51
Murlyn B. Dickerman	1951-63
David B. King	1963-72
John H. Ohman	1972-75

Director's Staff

Carlos. G. Bates, Silviculturist	1928-49
Sidney Weitzman, Division Chief	1957-67
Robert W. Merz, Assistant Director	1967-73
James Morgan, Assistant Director	1973
Arne K. Kemp, Assistant Director	1974-75

Project Staff

John Macon	1929-30
Joseph H. Stoeckeler, Forester	1930-33
Harold F. Scholz, Forester	1933-40
Robert G. Neu, Statistical Clerk	1939-40
Robert G. Nue, Statistical Clerk	1939-40
Joseph H. Stoeckeler, Soil Scientist	1958-63
Richard S. Sartz, Forester-Project Leader	1958-75
Janice M. Johnson, Secretary	1958-66
Willie R. Curtis, Forester	1959-66
David N. Tolsted, Forestry Technician	1962-75
Greta H. Lockhart, Administrative Clerk	1967-75
Boyd A. Hutchison, Forester	1967
Alfred Ray Harris, Soil Physicist	1968-75
M. Dean Knighton, Ecologist	1968-75

☆ U.S. Government Printing Office: 1978 768-691/33

Sartz, Richard S.

1978. Thirty years of soil and water research by the Forest Service in Wisconsin's Driftless Area—a history and annotated bibliography. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. NC-44, 18 p. North Cent. For Exp. Stn., St. Paul, Minnesota.

The history of forest watershed management research in the upper Mississippi Valley's unglaciated region, from its beginning in 1928 to its end in 1975, is narrated along with an annotated bibliography of the research accomplishments.

OXFORD: (048.1)116:116.6:114.12. KEY WORDS: Infiltration, hydrology, erosion, streamflow.

Sartz, Richard S.

1978. Thirty years of soil and water research by the Forest Service in Wisconsin's Driftless Area—a history and annotated bibliography. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. NC-44, 18 p. North Cent. For Exp. Stn., St. Paul, Minnesota.

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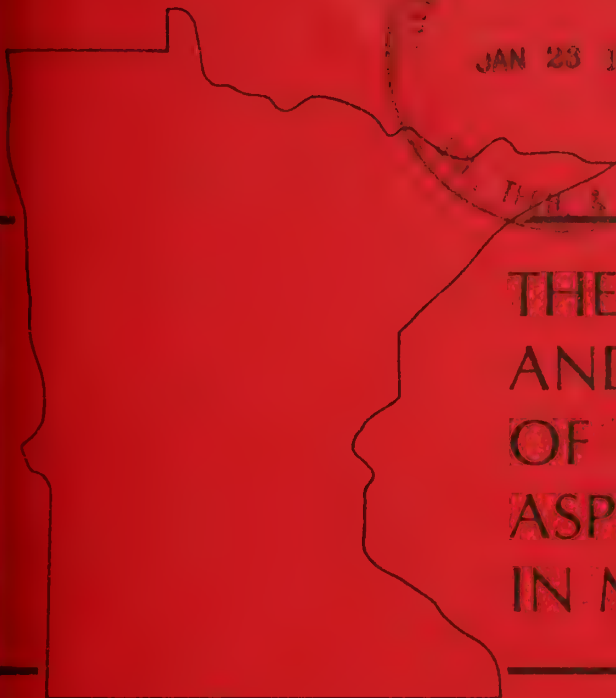

THE EXTENT AND CHARACTERISTICS OF LOW PRODUCTIVITY ASPEN AREAS IN MINNESOTA

Allen L. Lundgren and Jerold L. Hahn

Aspen
Birch
Conifer
PROGRAM REPORT

Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture

This paper is a contribution from the Aspen-Birch-Conifer Program. The Aspen-Birch-Conifer Program is a coordinated, multidisciplinary research effort. Its mission is to increase and integrate knowledge of the aspen-birch-conifer forests of the northern Great Lakes region in order to better identify and evaluate resource management alternatives.

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THE EXTENT AND CHARACTERISTICS OF LOW PRODUCTIVITY ASPEN AREAS IN WISCONSIN

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The aspen type in Wisconsin occupies about 3.7 million acres, 25 percent of the commercial forest land in the State. Aspen is a major pulpwood species in the State and during recent years has provided 40 to 45 percent of the total pulpwood. Because of the wide extent of the aspen type and importance of the timber industry, there is considerable interest in knowing the inherent capabilities of the aspen forest land.

Extensive areas of aspen in Wisconsin currently produce little commercial timber, either because of inherently low timber-growing potential for aspen or because they are understocked and are not capturing the full site potential. However, details about the extent and distribution of these low productivity areas have not been available. This report summarizes the extent and characteristics of "low productivity" aspen areas in Wisconsin and shows their location and general distribution. It considers both the inherent capacity of a site to grow timber (its potential productivity) and the percent of potential captured by the existing stand.

DATA BASE

The data for this study were taken from 1,592 plots classified as aspen type that were measured during the 1968 forest survey of Wisconsin on non-National Forest land (Spencer and Thorne 1972), and from 27 plots on the Chequamegon National Forest measured in 1974 and 37 plots on the Nicolet National Forest measured in 1975. Each plot consisted of 10 variable radius (37.5 Basal Area Factor prism) points equally spread over approximately 1 acre. Plot locations were determined by placing a systematic grid of 1-acre dots over an aerial photo mosaic of each township. To simplify the computing and to present the data for smaller geographically similar sections, the State was divided into five survey units (fig. 1).

The definition of the aspen type used by forest survey is "A stand in which a mixture of quaking or bigtooth aspen and balsam poplar, singly or in combination, comprises a plurality of the stocking".[1] To determine which of the plots measured in the three surveys were in the aspen type, the stocking of all live trees tallied on a plot was summarized by species and the plurality rule applied. However, a plot with a diversity of species was typed as aspen if stocking in aspen and paper birch in combination with other hardwood species exceeded the stocking of conifers, if aspen and paper birch combined exceeded other hardwood species, and if the aspen exceeded the paper birch.

Throughout this paper trees are described as all live or as growing stock. Live trees are those 1.0-inch d.b.h. or larger that are alive at the time tallied. They are further classified as desirable, acceptable, rough, rotten, or short log. Desirable trees have no serious defects that limit present or prospective use, have relatively high vigor, and

---

[1]*Stocking is the degree of utilization of land by trees as measured in terms of basal area and/or the number of trees in a stand compared to the basal area and/or number of trees required to utilize fully the growth potential of the land. For a thorough discussion of stocking, see Spencer and Thorne 1972, page 27.*

Figure 1.—*Survey units for the 1968 Wisconsin Forest Survey.*

contain no pathogens that may kill or seriously deteriorate them before rotation age. These are trees that would be favored by forest managers in silvicultural operations. Acceptable trees have no serious defects that limit present or prospective use but have pathogens or damage that may affect quality. The class of trees referred to as growing stock include only desirable and acceptable trees.

PRODUCTIVITY

The first step in the analysis was to establish th potential and actual productivity of each invent ry plot in Wisconsin in comparable units so eac plot could be characterized by the percent of i potential actually achieved. Site productivity i

expressed in cubic feet per acre per year. The cur-
rent productivity of a stand varies with its age, but
for a given rotation length productivity of a stand
can be expressed in terms of the mean annual
ncrement over the rotation. Site productivity typ-
cally is expressed by the maximum mean annual
ncrement over the range of rotation ages.

Yield tables from Kittredge and Gevorkiantz
1929), reporting total peeled cubic foot volume per
acre per year in trees 1-inch d.b.h. and larger in
well-stocked aspen stands, have been used for
nore than a decade as the standard for determin-
ng aspen site productivity in the Lake States, and
are used in this analysis.[2] An equation relating
naximum mean annual increment (MAI) in cubic
feet per acre per year to site index (S) was derived
rom the table data in Kittredge and Gevorkiantz
1929). A second-degree polynomial was fit to the
data for the five sites reported in the table to mini-
nize the squared differences between the derived
and predicted values and resulted in the following
equation:

$$MAI = -97.53 + 3.5463S - .014286\ S^2$$

We used this equation to estimate the MAI for
each plot from its recorded site index, and then we
used this MAI estimate to classify the plot's poten-
tial site productivity.

The actual productivity of each plot is more diffi-
cult to estimate. Present inventory procedures re-
quire that only merchantable volumes of growing
stock trees be recorded, whereas the MAI devel-
oped from the Kittredge and Gevorkiantz data
included total peeled volumes of all live trees 1.0-
inch d.b.h. and larger. Thus, the actual and poten-
tial volumes could not be compared directly.
Therefore, we decided to use basal area rather
than volume for our comparisons. All tree species,
not just aspen, are included in estimating percent
achievement.

Schlaegel (1971) derived an equation for esti-
mating the total stand cubic-foot yield per acre,
inside bark, for aspen (V) from total basal area in
square feet per acre (B) and average total height in
feet of dominants and codominants (H):

$$V = 0.41898\ HB$$

If we assume that stand height is the same for a
given age and site regardless of stand density,
then for a given age and site the total cubic volume
of a stand is directly proportional to the basal area
of the stand. That is,

$$V = kB$$

where $k = 0.41898\ H$

The actual volume in a stand (V_a) is estimated directly from its actual basal area (B_a), and the potential volume in a stand (V_p) is estimated from its potential basal area (B_p):

$$V_a = kB_a$$
$$V_p = kB_p$$

From these volume equations it is evident that the proportion of potential volume actually achieved, V_a/V_p, is identical to the proportion of basal area actually achieved, B_a/B_p, for a given age and site:

$$\frac{V_a}{V_p} = \frac{kB_a}{kB_p} = \frac{B_a}{B_p}$$

Using basal area, which is directly available from the plot records, to estimate the percent of potential productivity achieved eliminated extensive volume computations and adjustments.

We also had to determine at what point in the stand's development to compare the basal areas. The actual current annual increment recorded for each inventory plot cannot be compared directly with the potential MAI. Current increment is an average for only one recent growth period, whereas the MAI is an average for all growth periods throughout an entire rotation. Ideally, actual total production of a stand from its present age to the end of the rotation should be compared with its potential total production throughout the same period. With a one-final-harvest-cut system of management, as is used almost universally with aspen, the projected actual basal area at the time of harvest could be compared with its expected potential at the time of harvest to estimate the percent of potential the stand will achieve. But if understocked stands tend to approach full stocking with increasing age, using the current state of the stand would underestimate the stand's ultimate percent achievement of full productivity. To correct this deficiency current basal area must be projected to rotation.

Unfortunately, Schlaegel's (1971) equation for projecting aspen basal area growth covers only

[2]Mean annual increments derived from Ek and Brodie (1975) are from 10 to 15 percent lower than those reported by Kittredge and Gevorkiantz on site indexes 50 to 70, but they agree closely on site index 80.

sites greater than site index 65 and assumes that growth is the same on all sites. Although the growth rates given by Schlaegel's equation correspond reasonably well with those implied by the Kittredge and Gevorkiantz tables for older stands on better sites, they consistently give much higher basal area growths than shown by Kittredge and Gevorkiantz for poorer sites and younger ages. We decided to express the percent of full production achieved in terms of the current state of the stand rather than attempt projecting stand density to the end of the rotation.

The potential basal area per acre (B) at any given site index (S) and stand age (A) was estimated by the following equation:

$$B = 2.385\,S\,(1\text{-}e^{-0.031268A})$$

The parameters of this equation were determined by fitting a nonlinear function to the basal areas given by Kittredge and Gevorkiantz (1929) for all trees $\geqslant$1-inch d.b.h. in well-stocked aspen stands for a range of ages and sites. To estimate the proportion of potential achieved, the current basal area recorded for the inventory plot was divided by its potential estimated from the above equation. Using this equation, the estimated potential basal area of a 30-year-old stand on site index 70 would be 102 square feet/acre. If the actual basal area was 51 square feet/acre, the stand would have achieved only 50 percent of its potential, and would be so recorded.

The present basal area of a stand can be obtained directly from each plot record. But should the basal area include all live trees or should only growing-stock trees be included? The first provides a measure of apparent stocking of all trees in a stand and may be most appropriate for such harvest systems as full-tree chipping of all live trees. The second measures stocking of only those trees considered desirable and acceptable by traditional markets and harvesting systems. We used both measures and made separate sets of tables for each. When using the tables, keep in mind the distinction between the two measures of potential achievement.

EXTENT OF LOW PRODUCTIVITY AREAS

The stand age, site productivity, and percent of potential achieved were determined for each inventory plot classed as aspen type. The percent of achievement was based on the basal area of (1) a live trees >1.0-inch d.b.h. (tables 1-6, p. 13-18) an (2) growing stock trees only (tables 7-12, p. 19-2 The total acres within each age and potential pr ductivity class are the same for both methods computation, but the distribution of acres amo achievement classes differs.

We did not attempt to define what constitutes "low productivity area". But a broad definition low productivity can be specified and the numb of acres that fall in that class in the State or one the survey units can be determined (tables 1-1 For example, if a low productivity area is defin as one with a potential for growing less than cubic feet/acre/year, then in the State of Wiscons there are 236,000 acres of such "low productivit stands (table 7) of all ages out of a total 3,715,000 acres. Or, low productivity could be d fined as all stands with a potential of less than cubic feet/acre/year *and* all stands present achieving less than 50 percent of potential bas on growing stock. In this case you would determi the total acres of "low productivity" areas in t State by adding up all acres with 60 cubic fe acre/year or less potential (236,000 + 774,000 1,010,000 acres) and those areas with more th 60 cubic feet/acre/year that are producing at percent or less of potential (1,178,000 acres) to g a total "low productivity" area in Wisconsin 2,188,000 acres. When adding up both low site a low achievement areas, do not double count tho acres that are both low site *and* low achievemen

LOCATION OF LOW PRODUCTIVITY AREAS

Maps showing the location of aspen plots township and range in Wisconsin were prepar by computer printout for selected categories plots. These maps provide a visual impression plot locations and help identify areas with a co centration of special categories of aspen plots. map showing the location of all inventory plots Wisconsin typed as aspen in the 1968 survey pr vides a visual standard for comparing all the oth maps (fig. 2). This map and all other maps measu percent of productivity achieved in terms of gro ing stock basal area, not the basal area of all li trees.

Figure 3 shows the location of plots with t lowest site productivity potential; they are capa

Figure 2.—*Location of all inventory plots in the 1968 Wisconsin Forest Survey typed as aspen.*

of growing <40 cubic feet/acre/year. For the plots shown on this map, timber production from aspen stands would be low even if full potential could be achieved. The bulk of these plots were concentrated in two areas — one in north-central Wisconsin (extending roughly from Tomahawk to Park Falls), and one in central Wisconsin (roughly from Wisconsin Rapids to Eau Claire).

Figure 4 shows the location of plots in the lowest achievement-percent class; these plots are achieving <25 percent of their potential. This map indicates where timber production could be increased substantially if full potential could be achieved. Again areas of concentration are evident, particularly an area in the north central part of the State (extending roughly from Tomahawk to Hayward).

Figure 5 shows the location of plots on the best sites; these plots are capable of growing >80 cubic feet/acre/year but are currently achieving less than half of their potential. The stands represented by these plots occupy some of the best sites, but currently fall short of fully utilizing the site potential for timber production. Most of these high-potential areas are in the north central part of the State.

DISCUSSION

In Wisconsin, 1.7 million acres of aspen (47 percent of the total 3.7 million acres in aspen) achieve less than half of their potential, if only growing stock trees are considered (table 13). Even if all live trees are included, 1.0 million acres (27 percent of the aspen type) achieve less than half of their potential. Thus, aspen stands in Wisconsin currently produce only slightly more than half their potential growing stock timber.

If it were desirable and possible to reach full production from all of the aspen type, inventories of aspen growing stock would be at least 80 percent higher than they are currently. But attaining full stocking on all acres of aspen type may be an unrealistic goal (Bruce 1977, Spurr and Vaux 1976). Insect and disease epidemics, windstorms, drought, and many other factors may all contribute to understocking and make full stocking on every acre an unattainable goal. Research is needed to determine why these large areas are understocked and to suggest measures that could be taken to improve stocking.

The site potentials outlined in this paper appear reasonable. A sizable portion of plots closely approach their "potential" for the entire range of sites and ages. For example, 45 percent of the 1,656 aspen plots in Wisconsin had more than three-quarters of their potential basal area in all live trees. Twenty-two percent of all the aspen plots had *more* than their indicated potential, if all live trees are included. Even if only growing stock basal area is considered, 12 percent of all the plots exceeded the potential indicated for their specific site and age. This strongly indicates that the potential productivities used in this report are realistic goals to use.

Thirty-eight percent of the aspen type is capable of growing >80 cubic feet/acre/year (total cubic foot volume of the entire peeled stem). Seventy-three percent of the type can produce more than 60 cubic feet/acre/year, and 94 percent can produce more than 40 cubic feet/acre/year. Only 6 percent of the type is capable of producing <40 cubic feet/acre/year. The sites capable of growing <60 cubic feet/acre/year occupy 27 percent of the aspen type and would, if fully stocked, produce only 17 percent of the potential volume from the type.

If full potential stocking could be attained, 45 percent of the best site aspen land fully stocked with growing stock trees would produce as much volume as the entire aspen type in the State currently produces.

Table 13.—*Aspen area by achievement classes, 1968 Wisconsin survey*

Survey Unit	0-25	26-50	51-75	76+	Aspen area
	Percent achievement class				
	(percent)				(acres)
TOTAL BASAL AREA					
Northeastern	7	19	28	47	1,207,000
Northwestern	9	21	27	43	1,627,000
Central	10	12	32	45	699,000
Southwestern	0	22	27	51	78,000
Southeastern	11	17	25	47	104,000
GROWING STOCK BASAL AREA					
Northeastern	14	26	29	31	1,207,000
Northwestern	20	30	22	28	1,627,000
Central	21	28	31	21	699,000
Southwestern	18	33	33	14	78,000
Southeastern	28	27	28	17	104,000

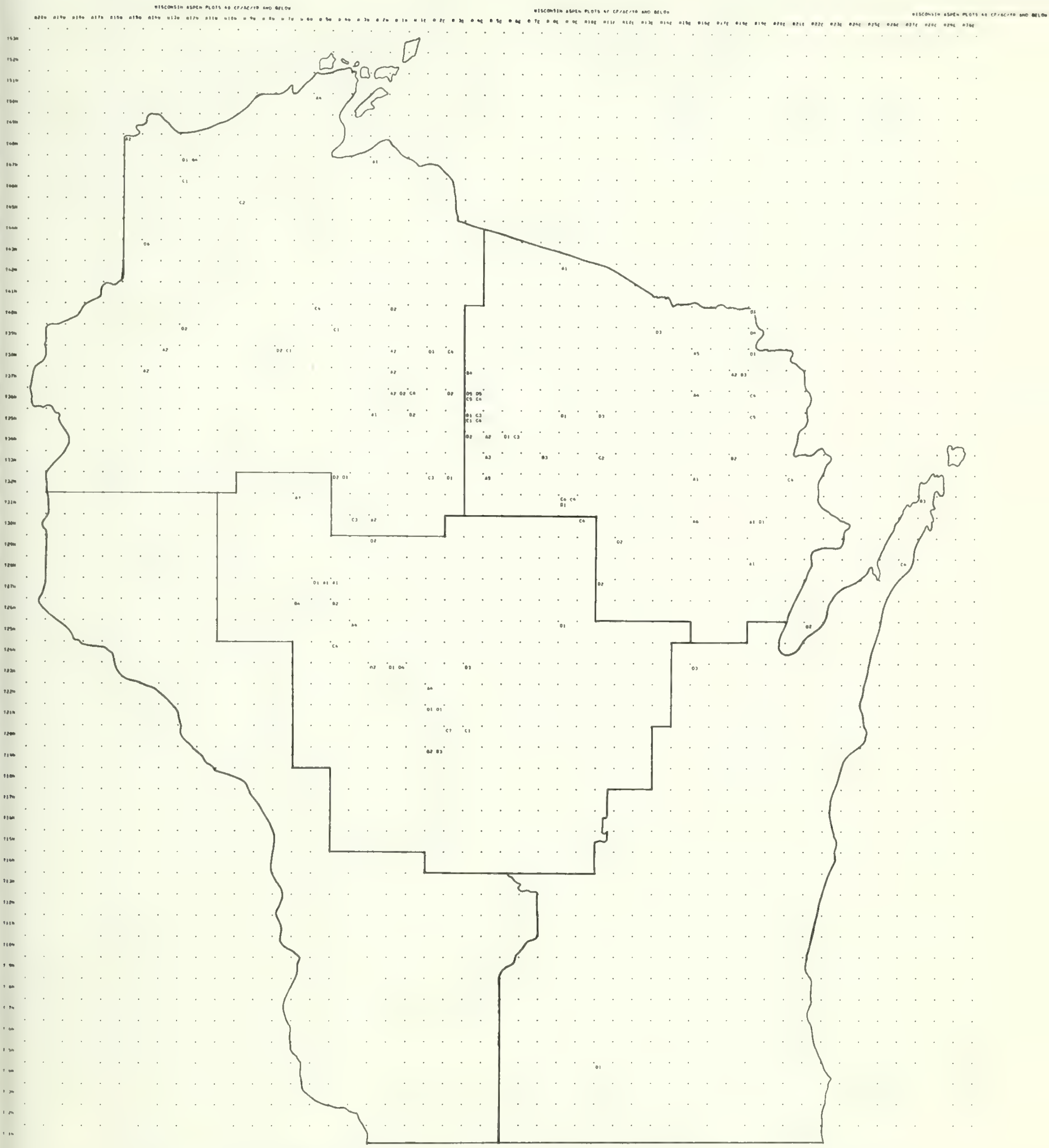

Figure 3.—*Location of all aspen plots in Wisconsin's 1968 Survey with the potential for growing ≤40 cubic feet per acre per year.*

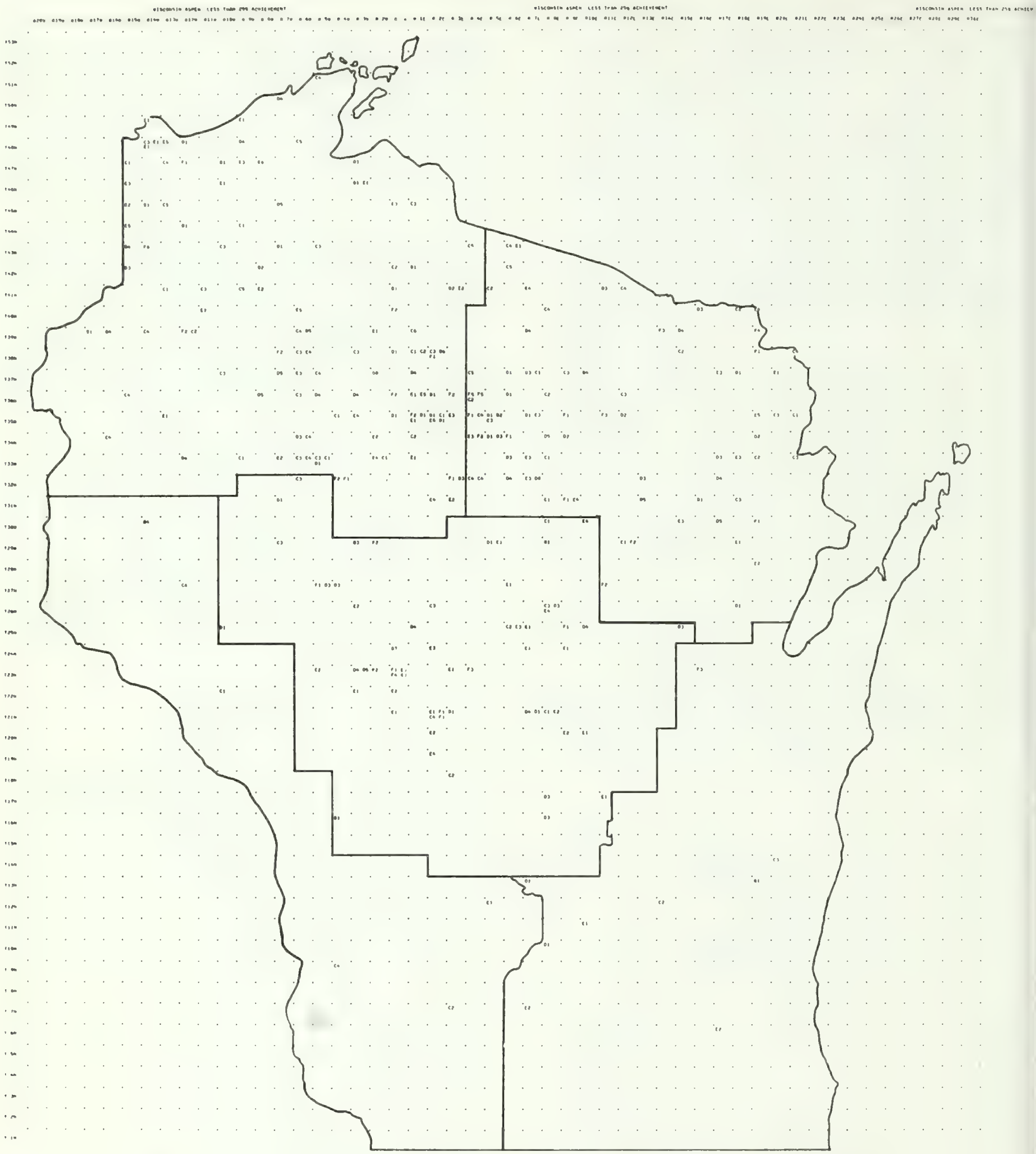

Figure 4.—*Location of all aspen plots in Wisconsin's 1968 Forest Survey achieving ≤25 percent of potential.*

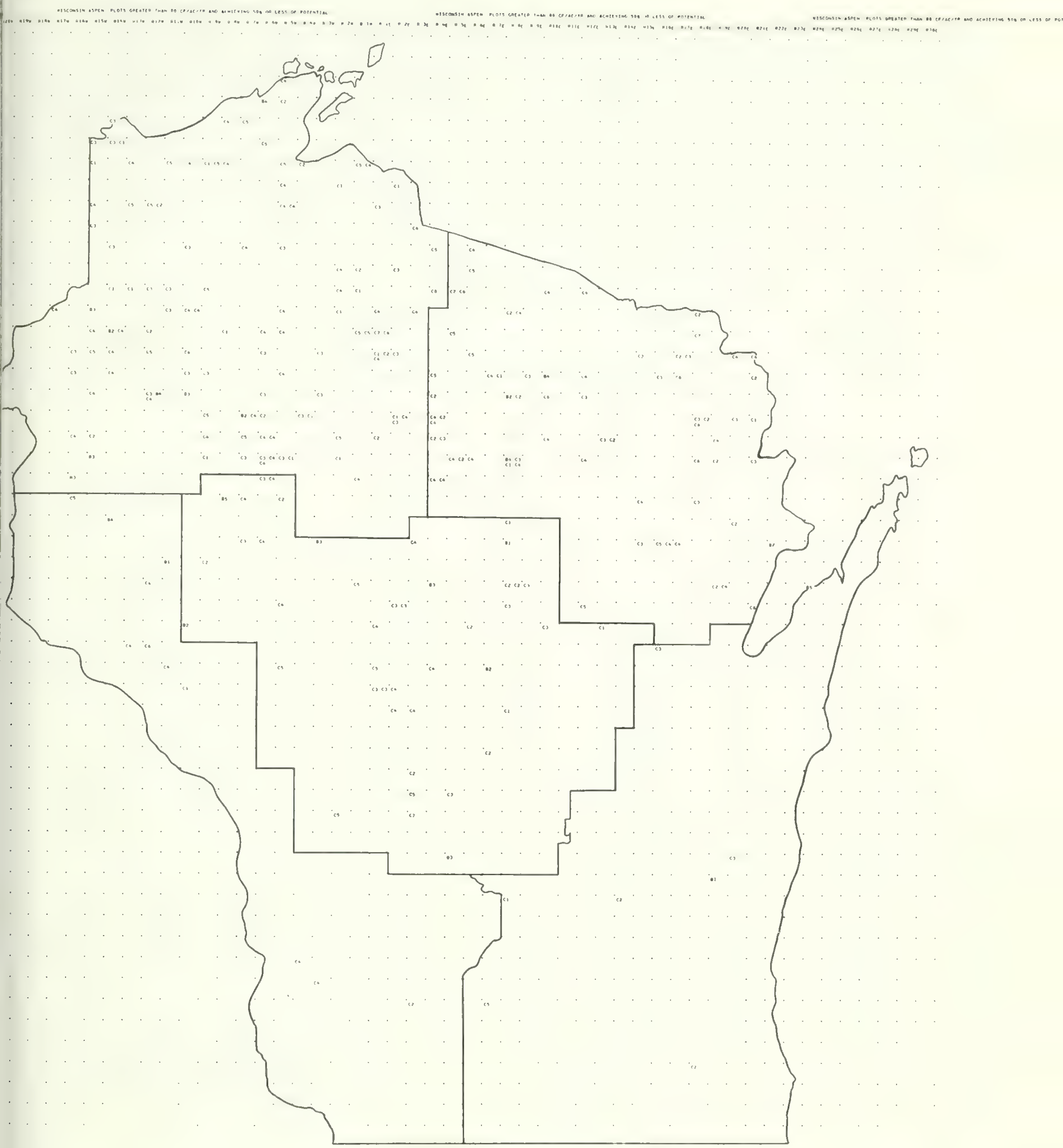

Figure 5.—*Location of all aspen plots in Wisconsin's 1968 Forest Survey capable of growing 80 cubic feet per acre per year but achieving ≤50 percent of their potential.*

To achieve full site potential in poorly-stocked aspen stands, the existing stand may have to be removed and regenerated by appropriate site preparation. But it may not be desirable to regenerate all sites to aspen — some may be better adapted to another species or the cost of site preparation to ensure full stocking may exceed the benefit.

A summary of acres by physiographic class a site index for all aspen plots may give some cl about the potential for site conversion (tables and 15). Five physiographic classes were used the Wisconsin inventory, ranging from xeric (v dry droughty sites) through mesic (deep, w drained soils favorable to tree growth) to hyd (where growth and number of species are seriou limited by excess water).

Table 14.—*Area of aspen type in Wisconsin by physiograph class, potential productivity class, and percent-achievement class, 1968 survey*[1]

Potential cubic feet/ acre/year	Potential achieved[2]	Physiographic Class Xeromesic	Mesic	Hydromesic	Hydric	Tot
	Percent	Thousand acres				
101-120	0-25	0	9	2	0	1
	26-50	2	30	9	0	4
	51-75	0	42	9	0	5
	76+	0	25	0	0	2
	TOTAL	2	107	20	0	12
81-100	0-25	7	138	51	5	20
	26-50	9	268	81	6	36
	51-75	11	310	50	2	37
	76+	9	285	60	0	35
	TOTAL	36	1,000	241	13	1,29
61-80	0-25	8	128	50	9	19
	26-50	15	242	102	6	36
	51-75	12	275	74	0	36
	76+	7	303	55	0	36
	TOTAL	42	948	281	15	1,28
41-60	0-25	7	111	73	2	19
	26-50	11	113	77	5	20
	51-75	6	114	43	8	17
	76+	7	146	47	3	20
	TOTAL	31	485	241	17	77
21-40	0-25	7	16	53	9	8
	26-50	0	41	16	10	6
	51-75	3	15	5	3	2
	76+	2	36	20	0	5
	TOTAL	12	108	94	22	23
TOTAL	0-25	29	402	229	25	68
	26-50	38	695	285	27	1,04
	51-75	32	756	180	13	98
	76+	24	795	182	3	1,00
	TOTAL	124	2,648	876	67	3,71

[1]Columns may not add due to rounding.
[2]Based on all live trees.

Table 15.—*Area of aspen type in Wisconsin by physiograph class, potential productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/acre/year	Potential achieved[2]	Physiographic Class				
		Xeromesic	Mesic	Hydromesic	Hydric	Total
	Percent	Thousand acres				
101-120	0-25	0	5	0	0	5
	26-50	0	18	4	0	22
	51-75	2	31	7	0	40
	76+	0	52	9	0	61
	TOTAL	2	107	20	0	129
81-100	0-25	2	48	31	2	83
	26-50	9	185	71	9	274
	51-75	9	294	48	0	351
	76+	15	473	91	2	582
	TOTAL	36	1,000	241	13	1,290
61-80	0-25	6	45	27	7	86
	26-50	4	128	61	2	196
	51-75	15	311	84	4	414
	76+	16	463	108	2	590
	TOTAL	42	948	281	15	1,286
41-60	0-25	2	36	45	0	83
	26-50	7	80	42	5	133
	51-75	7	122	58	8	195
	76+	16	246	96	5	363
	TOTAL	31	485	241	17	774
21-40	0-25	7	7	28	9	51
	26-50	0	27	26	6	59
	51-75	0	29	17	4	51
	76+	6	45	22	3	75
	TOTAL	12	108	94	22	236
TOTAL	0-25	17	141	131	18	308
	26-50	20	438	205	21	684
	51-75	34	789	213	16	1,051
	76+	52	1,280	327	12	1,672
	TOTAL	124	2,648	876	67	3,715

[1]Columns may not add due to rounding.
[2]Based on growing-stock trees only.

No aspen plots were characterized as xeric, so only four classes are presented here — xeromesic, mesic, hydromesic, and hydric. Seventy-one percent of all aspen plots were classed as mesic, 24 percent were hydromesic, 3 percent were xeromesic, and 2 percent were hydric. Mesic plots had the highest average site index (67) and thus the highest potential productivity (76 cubic feet/acre/year). Xeromesic was next (SI 63, 69 cubic feet/acre/year), then hydromesic (SI 61, 66 cubic feet/acre/year), and last hydric (SI 57, 58 cubic feet/acre/year). Only 41 percent of the mesic plots achieved less than half their potential in growing-stock trees, but 54 percent of the xeromesic plots, 59 percent of the hydromesic plots, and 78 percent of the hydric plots attained less than half their potential. Thirty percent of the mesic plots and only 4 percent of the hydric plots achieved more than 75 percent of their potential. These data indicate that mesic plots tend to have the highest potential for aspen and highest achievement of potential, and the hydric plots the lowest potential and the lowest achievement of potential.

A look at the distribution of plots by achievement class within the State reveals some interesting differences among survey units (table 13). If all live trees are counted, roughly 45 to 50 percent of the plots in each survey unit attain more than 75 percent of their potential. However, if only growing stock basal area is counted, then the percentage of plots achieving 75 percent of their potential is different between survey units — 30 percent in the northern units, 20 percent in the central unit, and about 15 percent in the southern units. Apparently the percentage of nongrowing-stock trees in aspen stands increases from north to south. Understocking of growing-stock trees appears to be more of a problem in the southern part of the State than it is in the north, but only 5 percent of the State's aspen type is in these two southern units.

The percent of stands achieving less than 50 percent of their potential does vary with stand age, but there is no discernable age trend.

CONCLUSIONS

Much forest area classified as aspen type in Wi consin is capable of producing high cubic-foot vo umes but is currently achieving less than it potential. If all aspen stands were fully stocke with growing-stock trees and achieved their fu potential, the present inventory of aspen growin stock would be approximately 80 percent highe than it is now. The possibilities and techniques fo reaching full stocking on aspen sites for a wid range of conditions need to be researche Whether full productivity is economically, ecolog cally, or environmentally feasible also must b determined.

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Table 1.—*Area of aspen type in Wisconsin by stand age class, potential site productivity class, and percent-of-achievement class, 1968 survey*

Potential cubic feet/ acre/year	Potential achieved[1]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	[2]5	0	0	0	0	0	0	0	5
	26-50	0	7	7	9	0	0	0	0	22
	51-75	0	5	9	17	9	0	0	0	40
	76+	12	18	16	11	5	0	0	0	61
	TOTAL	17	30	31	37	14	0	0	0	129
81-100	0-25	[2]38	14	18	10	2	0	0	0	83
	26-50	19	32	51	113	40	12	4	2	274
	51-75	11	40	69	140	80	9	0	2	351
	76+	112	114	72	179	88	11	6	0	582
	TOTAL	181	200	210	442	211	32	11	4	129
61-80	0-25	[2]40	9	15	13	4	0	0	4	86
	26-50	25	12	23	80	51	4	2	0	196
	51-75	32	48	60	143	102	24	4	2	414
	76+	175	92	42	144	101	33	2	0	590
	TOTAL	272	161	140	380	257	62	8	6	128
41-60	0-25	[2]43	12	21	2	2	3	0	0	83
	26-50	22	21	25	33	15	14	2	0	133
	51-75	26	38	25	45	44	10	7	0	195
	76+	142	60	27	75	39	12	4	4	363
	TOTAL	232	131	99	155	101	39	13	4	774
21-40	0-25	[2]30	15	2	0	2	2	0	0	51
	26-50	6	9	14	28	2	0	0	0	59
	51-75	8	9	7	18	4	0	2	2	51
	76+	19	32	7	9	4	2	2	0	75
	TOTAL	63	65	29	55	13	4	4	2	236
TOTAL	0-25	[2]156	50	57	25	10	5	0	4	308
	26-50	73	81	119	263	108	30	8	2	684
	51-75	77	139	170	363	239	43	13	6	1,051
	76+	460	315	164	418	238	59	15	4	1,672
	TOTAL	766	586	509	1,069	595	137	37	17	3,715

[1]Based on all live trees.

[2]Includes plots classed as nonstocked aspen type.

Table 2.—*Area of aspen type in Northeastern Survey Unit of Wisconsin, by stand age class, potential s productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	0	0	0	0	0	0	0	0	0
	26-50	0	5	0	2	0	0	0	0	7
	51-75	0	0	0	5	0	0	0	0	5
	76+	0	2	7	2	0	0	0	0	11
	TOTAL	0	7	7	9	0	0	0	0	23
81-100	0-25	[3]4	7	2	4	2	0	0	0	19
	26-50	2	14	14	36	2	9	2	0	79
	51-75	0	16	13	43	35	2	0	2	111
	76+	40	40	17	39	27	6	4	0	172
	TOTAL	46	76	46	122	66	17	6	2	382
61-80	0-25	[3]9	6	8	5	2	0	0	2	32
	26-50	8	2	13	36	25	0	0	0	84
	51-75	6	11	23	38	33	8	0	2	120
	76+	59	22	15	69	58	12	0	0	234
	TOTAL	82	42	59	148	117	20	0	4	471
41-60	0-25	[3]2	0	8	2	0	0	0	0	12
	26-50	6	6	12	7	0	4	0	0	34
	51-75	4	7	10	22	29	6	2	0	79
	76+	34	21	8	23	22	10	2	2	122
	TOTAL	45	34	38	54	51	19	4	2	247
21-40	0-25	[3]11	2	2	0	2	0	0	0	17
	26-50	2	4	6	8	2	0	0	0	23
	51-75	2	4	2	9	4	0	0	0	21
	76+	7	5	4	2	4	2	0	0	25
	TOTAL	22	16	14	19	13	2	0	0	86
TOTAL	0-25	[3]26	15	20	11	6	0	0	2	80
	26-50	17	31	46	89	29	13	2	0	227
	51-75	11	38	48	116	100	15	2	4	336
	76+	140	90	51	136	111	30	6	2	565
	TOTAL	194	174	164	352	246	58	11	8	1,207

[1]Columns may not add due to rounding.
[2]Based on all live trees.
[3]Includes plots classed as nonstocked aspen type.

Table 3.—*Area of aspen type in Northwestern Survey Unit of Wisconsin, by stand age class, potential site productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	0	0	0	0	0	0	0	0	0
	26-50	0	3	2	4	0	0	0	0	9
	51-75	0	0	7	8	0	0	0	0	15
	76+	4	7	7	6	0	0	0	0	24
	Total	4	10	16	19	0	0	0	0	49
81-100	0-25	[3]30	3	12	6	0	0	0	0	50
	26-50	15	10	27	66	29	3	2	2	154
	51-75	8	7	33	56	36	4	0	0	145
	76+	44	59	36	108	43	2	2	0	295
	Total	97	79	108	237	108	9	4	2	645
61-80	0-25	[3]22	3	0	8	2	0	0	2	37
	26-50	13	5	7	29	24	4	0	0	82
	51-75	21	30	20	66	53	17	4	0	211
	76+	83	31	11	52	34	17	0	0	228
	Total	138	69	38	155	114	37	4	2	558
41-60	0-25	[3]22	5	11	0	2	3	0	0	43
	26-50	12	7	7	18	13	10	2	0	69
	51-75	19	17	0	2	11	2	2	0	55
	76+	65	27	2	19	11	2	2	0	128
	Total	118	57	20	39	37	17	7	0	294
21-40	0-25	[3]4	10	0	0	0	2	0	0	17
	26-50	4	3	2	12	0	0	0	0	21
	51-75	7	2	2	2	0	0	0	2	16
	76+	4	22	0	2	0	0	0	0	28
	Total	20	37	5	16	0	2	0	2	81
TOTAL	0-25	[3]77	20	23	14	4	5	0	2	146
	26-50	43	27	45	130	66	17	5	2	335
	51-75	55	57	62	135	100	23	7	2	442
	76+	200	146	56	187	88	21	4	0	704
	Total	376	251	187	467	259	66	15	7	1,627

[1]Columns may not add due to rounding.
[2]Based on all live trees.
[3]Includes plots classed as nonstocked aspen type.

Table 4.—*Area of aspen type in Central Survey Unit of Wisconsin, by stand age class, potential site productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/ acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	[3]2	0	0	0	0	0	0	0	2
	26-50	0	0	4	0	0	0	0	0	4
	51-75	0	5	2	2	2	0	0	0	12
	76+	2	5	2	2	2	0	0	0	14
	Total	5	10	9	5	4	0	0	0	32
81-100	0-25	[3]5	5	5	0	0	0	0	0	14
	26-50	0	2	7	7	7	0	0	0	23
	51-75	2	17	14	34	4	0	0	0	71
	76+	19	9	14	30	16	0	0	0	88
	Total	27	33	39	71	27	0	0	0	197
61-80	0-25	[3]10	0	7	0	0	0	0	0	17
	26-50	2	5	2	15	2	0	2	0	28
	51-75	2	7	16	39	15	0	0	0	80
	76+	17	36	17	18	9	2	2	0	101
	Total	32	48	42	71	26	2	4	0	226
41-60	0-25	[3]15	5	2	0	0	0	0	0	22
	26-50	2	7	4	8	2	0	0	0	24
	51-75	2	7	12	18	5	2	2	0	49
	76+	37	12	17	23	5	0	0	2	95
	Total	56	32	35	50	11	2	2	2	191
21-40	0-25	[3]13	2	0	0	0	0	0	0	15
	26-50	0	2	2	2	0	0	0	0	7
	51-75	0	2	2	7	0	0	2	0	14
	76+	7	2	0	5	0	0	2	0	17
	Total	20	9	5	14	0	0	4	0	53
TOTAL	0-25	[3]45	12	14	0	0	0	0	0	71
	26-50	5	17	20	32	11	0	2	0	87
	51-75	7	39	46	100	27	2	4	0	226
	76+	83	64	50	78	31	2	4	2	315
	Total	140	132	131	211	69	5	10	2	699

[1]Columns may not add due to rounding.
[2]Based on all live trees.
[3]Includes plots classed as nonstocked aspen type.

Table 5.—*Area of aspen type in Southwestern Survey Unit of Wisconsin, by stand age class, potential site productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/ acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	0	0	0	0	0	0	0	0	0
	26-50	0	0	0	2	0	0	0	0	2
	51-75	0	0	0	2	5	0	0	0	7
	76+	6	3	0	0	3	0	0	0	12
	Total	6	3	0	4	7	0	0	0	21
81-100	0-25	0	0	0	0	0	0	0	0	0
	26-50	3	3	0	4	2	0	0	0	12
	51-75	0	0	2	6	0	3	0	0	11
	76+	3	0	0	2	3	3	0	0	11
	Total	6	3	2	12	5	5	0	0	33
61-80	0-25	0	0	0	0	0	0	0	0	0
	26-50	0	0	0	0	0	0	0	0	0
	51-75	0	0	0	0	0	0	0	0	0
	76+	2	0	0	2	0	3	0	0	7
	Total	2	0	0	2	0	3	0	0	7
41-60	0-25	0	0	0	0	0	0	0	0	0
	26-50	3	0	0	0	0	0	0	0	3
	51-75	0	0	3	0	0	0	0	0	3
	76+	6	0	0	2	2	0	0	0	11
	Total	9	0	3	2	2	0	0	0	17
21-40	0-25	0	0	0	0	0	0	0	0	0
	26-50	0	0	0	0	0	0	0	0	0
	51-75	0	0	0	0	0	0	0	0	0
	76+	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0
TOTAL	0-25	0	0	0	0	0	0	0	0	0
	26-50	5	3	0	7	2	0	0	0	17
	51-75	0	0	5	8	5	3	0	0	21
	76+	18	3	0	6	7	5	0	0	40
	Total	23	6	5	21	14	8	0	0	78

[1]Columns may not add due to rounding.
[2]Based on all live trees.

Table 6.—*Area of aspen type in Southeastern Survey Unit of Wisconsin, by stand age class, potential s[ite] productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/ acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	[3]2	0	0	0	0	0	0	0	2
	26-50	0	0	0	0	0	0	0	0	0
	51-75	0	0	0	0	2	0	0	0	2
	76+	0	0	0	0	0	0	0	0	0
	Total	2	0	0	0	2	0	0	0	5
81-100	0-25	0	0	0	0	0	0	0	0	0
	26-50	0	3	2	0	0	0	0	0	5
	51-75	0	0	8	0	5	0	0	0	13
	76+	5	6	4	0	0	0	0	0	16
	Total	5	9	14	0	5	0	0	0	33
61-80	0-25	0	0	0	0	0	0	0	0	0
	26-50	2	0	0	0	0	0	0	0	2
	51-75	3	0	0	0	0	0	0	0	3
	76+	13	3	0	3	0	0	0	0	20
	Total	19	3	0	3	0	0	0	0	25
41-60	0-25	[3]4	2	0	0	0	0	0	0	6
	26-50	0	0	3	0	0	0	0	0	3
	51-75	0	6	0	3	0	0	0	0	9
	76+	0	0	0	7	0	0	0	0	7
	Total	4	8	3	10	0	0	0	0	25
21-40	0-25	[3]2	0	0	0	0	0	0	0	2
	26-50	0	0	2	6	0	0	0	0	8
	51-75	0	0	0	0	0	0	0	0	0
	76+	0	3	3	0	0	0	0	0	6
	Total	2	3	5	6	0	0	0	0	16
TOTAL	0-25	[3]8	2	0	0	0	0	0	0	11
	26-50	2	3	8	6	0	0	0	0	18
	51-75	3	6	8	3	7	0	0	0	26
	76+	19	12	7	10	0	0	0	0	49
	Total	32	23	22	19	7	0	0	0	104

[1]Columns may not add due to rounding.
[2]Based on all live trees.
[3]Includes plots classed as nonstocked aspen type.

Table 7.—*Area of aspen type in Wisconsin by stand age class, potential site productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	[3]5	0	2	4	0	0	0	0	11
	26-50	2	14	14	6	5	0	0	0	41
	51-75	8	6	9	21	7	0	0	0	51
	76+	2	10	7	4	3	0	0	0	25
	Total	17	30	31	37	14	0	0	0	129
81-100	0-25	[3]49	33	57	38	20	3	0	0	200
	26-50	22	52	65	142	60	14	4	4	364
	51-75	30	47	59	167	63	6	0	0	373
	76+	79	67	29	95	68	9	6	0	353
	Total	181	200	210	442	211	32	11	4	1,290
61-80	0-25	[3]71	16	34	34	33	2	2	4	196
	26-50	46	47	40	140	64	24	2	2	366
	51-75	39	61	40	117	85	14	4	0	360
	76+	117	37	26	88	74	22	0	0	365
	Total	272	161	140	380	257	62	8	6	1,286
41-60	0-25	[3]72	37	41	28	11	5	0	0	194
	26-50	41	33	32	40	35	18	7	0	206
	51-75	31	26	17	53	31	8	2	2	171
	76+	88	33	9	34	24	8	4	2	203
	Total	232	131	99	155	101	39	13	4	774
21-40	0-25	[3]36	29	9	4	4	2	0	0	85
	26-50	11	5	8	35	4	0	2	2	67
	51-75	0	10	9	7	0	0	0	0	26
	76+	16	21	2	9	4	2	2	0	58
	Total	63	65	29	55	13	4	4	2	236
TOTAL	0-25	[3]233	115	143	109	67	12	2	4	686
	26-50	122	152	159	364	168	56	15	8	1,044
	51-75	108	151	133	366	186	29	7	2	981
	76+	302	168	74	231	174	40	13	2	1,004
	Total	766	586	509	1,069	595	137	37	17	3,715

[1]Columns may not add due to rounding.
[2]Based on growing-stock trees only.
[3]Includes plots classed as nonstocked aspen type.

Table 8.—*Area of aspen type in Northeastern Survey Unit of Wisconsin, by stand age class, potential s productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	0	0	0	2	0	0	0	0	2
	26-50	0	5	0	2	0	0	0	0	7
	51-75	0	0	4	2	0	0	0	0	7
	76+	0	2	2	2	0	0	0	0	7
	Total	0	7	7	9	0	0	0	0	23
81-100	0-25	[3]6	13	10	15	4	0	0	0	47
	26-50	0	23	13	38	11	9	2	2	99
	51-75	12	21	17	48	27	4	0	0	129
	76+	28	19	7	21	25	4	4	0	106
	Total	46	76	46	122	66	17	6	2	382
61-80	0-25	[3]15	8	13	9	9	0	0	2	57
	26-50	6	8	19	51	26	8	0	2	120
	51-75	12	15	14	38	44	2	0	0	126
	76+	49	10	13	49	38	10	0	0	168
	Total	82	42	59	148	117	20	0	4	471
41-60	0-25	[3]9	2	18	6	2	0	0	0	37
	26-50	10	6	8	18	11	6	2	0	60
	51-75	6	12	8	19	24	6	0	0	74
	76+	20	14	5	11	13	8	2	2	75
	Total	45	34	38	54	51	19	4	2	247
21-40	0-25	[3]13	6	4	2	4	0	0	0	30
	26-50	2	2	4	12	4	0	0	0	24
	51-75	0	2	4	2	0	0	0	0	8
	76+	7	5	2	2	4	2	0	0	23
	Total	22	16	14	19	13	2	0	0	86
TOTAL	0-25	[3]42	30	45	35	19	0	0	2	173
	26-50	18	45	43	122	52	23	4	4	310
	51-75	30	49	47	110	95	12	0	0	344
	76+	104	50	28	86	80	24	6	2	380
	Total	194	174	164	352	246	58	11	8	1,207

[1]Columns may not add due to rounding.

[2]Based on growing-stock trees only.

[3]Includes plots classed as nonstocked aspen type.

Table 9.—*Area of aspen type in Northwestern Survey Unit of Wisconsin, by stand age class, potential site productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/ acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	Thousand acres								
101-120	0-25	0	0	0	0	0	0	0	0	0
	26-50	0	5	9	4	0	0	0	0	18
	51-75	2	0	4	13	0	0	0	0	19
	76+	2	5	2	2	0	0	0	0	11
	Total	4	10	16	19	0	0	0	0	49
81-100	0-25	[3]36	10	36	17	16	3	0	0	117
	26-50	17	12	34	77	34	2	2	2	180
	51-75	11	15	23	90	26	2	0	0	166
	76+	33	42	16	54	32	2	2	0	182
	Total	97	79	108	237	108	9	4	2	645
61-80	0-25	[3]37	7	7	16	22	2	0	2	93
	26-50	28	15	16	60	32	17	2	0	170
	51-75	19	29	9	49	30	7	2	0	146
	76+	55	17	7	29	30	12	0	0	149
	Total	138	69	38	155	114	37	4	2	558
41-60	0-25	[3]31	12	14	16	9	5	0	0	86
	26-50	26	22	7	4	17	10	5	0	91
	51-75	15	5	0	6	2	2	0	0	30
	76+	46	17	0	12	9	0	2	0	86
	Total	118	57	20	39	37	17	7	0	294
21-40	0-25	[3]9	17	0	0	0	2	0	0	29
	26-50	6	2	5	12	0	0	0	2	28
	51-75	0	0	0	2	0	0	0	0	2
	76+	4	17	0	2	0	0	0	0	23
	Total	20	37	5	16	0	2	0	2	81
TOTAL	0-25	[3]112	47	56	49	46	12	0	2	325
	26-50	77	57	70	158	83	28	9	4	487
	51-75	46	49	36	160	58	12	2	0	364
	76+	140	97	25	100	71	14	4	0	451
	Total	376	251	187	467	429	66	15	7	1,627

[1]Columns may not add due to rounding.
[2]Based on growing-stock trees only.
[3]Includes plots classed as nonstocked aspen type.

Table 10.—*Area of aspen type in Central Survey Unit of Wisconsin, by stand age class, potential site productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/ acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	[3]2	0	2	0	0	0	0	0	4
	26-50	0	5	5	0	2	0	0	0	12
	51-75	2	2	0	5	2	0	0	0	12
	76+	0	2	2	0	0	0	0	0	5
	Total	5	10	9	5	4	0	0	0	32
81-100	0-25	[3]5	5	9	2	0	0	0	0	21
	26-50	2	14	14	21	11	0	0	0	62
	51-75	7	12	9	30	5	0	0	0	63
	76+	12	2	7	18	11	0	0	0	51
	Total	27	33	39	71	27	0	0	0	197
61-80	0-25	[3]15	0	14	9	2	0	2	0	41
	26-50	5	24	5	28	6	0	0	0	68
	51-75	2	17	16	27	11	2	2	0	79
	76+	10	7	7	7	7	0	0	0	38
	Total	32	48	42	71	26	2	4	0	226
41-60	0-25	[3]25	15	9	6	0	0	0	0	55
	26-50	2	5	11	16	4	2	0	0	42
	51-75	7	10	10	20	5	0	2	2	56
	76+	22	2	5	7	2	0	0	0	38
	Total	56	32	35	50	11	2	2	2	191
21-40	0-25	[3]13	5	2	2	0	0	0	0	23
	26-50	2	0	0	5	0	0	2	0	9
	51-75	0	4	2	2	0	0	0	0	9
	76+	5	0	0	5	0	0	2	0	12
	Total	20	9	5	14	0	0	4	0	53
TOTAL	0-25	[3]60	24	37	19	2	0	2	0	144
	26-50	12	47	35	70	24	2	2	0	193
	51-75	19	45	37	84	22	2	4	2	218
	76+	49	14	21	37	21	0	2	0	144
	Total	140	132	131	211	69	5	10	2	699

[1]Columns may not add due to rounding.
[2]Based on growing-stock trees only.
[3]Includes plots classed as nonstocked aspen type.

Table 11.—*Area of aspen type in Southwestern Wisconsin, Survey Unit by stand age class, potential site productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/ acre/year	Potential achieved[2]	Stand Age 0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	All ages
	Percent	*Thousand acres*								
101-120	0-25	0	0	0	2	0	0	0	0	2
	26-50	2	0	0	0	0	0	0	0	2
	51-75	3	3	0	2	5	0	0	0	13
	76+	0	0	0	0	3	0	0	0	3
	Total	6	3	0	4	7	0	0	0	21
81-100	0-25	[3]3	3	0	4	0	0	0	0	9
	26-50	0	0	0	7	2	3	0	0	11
	51-75	0	0	2	0	3	0	0	0	5
	76+	3	0	0	2	0	3	0	0	8
	Total	6	3	2	12	5	5	0	0	33
61-80	0-25	0	0	0	0	0	0	0	0	0
	26-50	2	0	0	0	0	0	0	0	2
	51-75	0	0	0	2	0	3	0	0	5
	76+	0	0	0	0	0	0	0	0	0
	Total	2	0	0	2	0	3	0	0	7
41-60	0-25	[3]3	0	0	0	0	0	0	0	3
	26-50	3	0	3	2	2	0	0	0	10
	51-75	3	0	0	0	0	0	0	0	3
	76+	0	0	0	0	0	0	0	0	0
	Total	9	0	3	2	2	0	0	0	17
21-40	0-25	0	0	0	0	0	0	0	0	0
	26-50	0	0	0	0	0	0	0	0	0
	51-75	0	0	0	0	0	0	0	0	0
	76+	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0
TOTAL	0-25	[3]6	3	0	6	0	0	0	0	14
	26-50	7	0	3	9	4	3	0	0	26
	51-75	7	3	2	4	7	3	0	0	26
	76+	3	0	0	2	3	3	0	0	11
	Total	23	6	5	21	14	8	0	0	78

[1]Columns may not add due to rounding.
[2]Based on growing-stock trees only.
[3]Includes plots classed as nonstocked aspen type.

Table 12.—*Area of aspen type in Southeastern Survey Unit of Wisconsin by stand age class, potential s productivity class, and percent-of-achievement class, 1968 survey*[1]

Potential cubic feet/acre/year	Potential achieved[2]	Stand Age								All ages
		0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+	
	Percent	*Thousand acres*								
101-120	0-25	[3]2	0	0	0	0	0	0	0	2
	26-50	0	0	0	0	2	0	0	0	2
	51-75	0	0	0	0	0	0	0	0	0
	76+	0	0	0	0	0	0	0	0	0
	Total	2	0	0	0	3	0	0	0	5
81-100	0-25	[3]0	3	2	0	0	0	0	0	5
	26-50	3	3	4	0	2	0	0	0	12
	51-75	0	0	8	0	3	0	0	0	11
	76+	3	3	0	0	0	0	0	0	6
	Total	5	9	14	0	5	0	0	0	33
61-80	0-25	[3]5	0	0	0	0	0	0	0	5
	26-50	5	0	0	0	0	0	0	0	5
	51-75	5	0	0	0	0	0	0	0	5
	76+	3	3	0	3	0	0	0	0	9
	Total	19	3	0	3	0	0	0	0	25
41-60	0-25	[3]4	8	0	0	0	0	0	0	12
	26-50	0	0	3	0	0	0	0	0	3
	51-75	0	0	0	7	0	0	0	0	7
	76+	0	0	0	3	0	0	0	0	3
	Total	4	8	3	10	0	0	0	0	25
21-40	0-25	[3]2	0	2	0	0	0	0	0	4
	26-50	0	0	0	6	0	0	0	0	6
	51-75	0	3	3	0	0	0	0	0	6
	76+	0	0	0	0	0	0	0	0	0
	Total	2	3	5	6	0	0	0	0	16
TOTAL	0-25	[3]13	11	5	0	0	0	0	0	29
	26-50	8	3	7	6	4	0	0	0	28
	51-75	5	3	10	7	3	0	0	0	29
	76+	6	6	0	6	0	0	0	0	18
	Total	32	23	22	19	7	0	0	0	104

[1]Columns may not add due to rounding.
[2]Based on growing-stock trees only.
[3]Includes plots classed as nonstocked aspen type.

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